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50TH YEAR OF PUBLICATION

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50TH YEAR OF PUBLICATION

This issue of *Southern Stars* marks 50 years of publication. It is therefore opportune to make brief mention of its history, and those individuals who have given of their time and energy to the interesting, generally rewarding, but often thankless job of editing and preparing submitted articles for publication.

Southern Stars commenced publication in November 1934, and was issued monthly. In addition a regular cyclostyled *'Monthly Notes of the Society'* containing "...articles and paragraphs...such as might be of interest to advanced readers as well as beginners...", which was first published many years earlier, continued to be distributed. This was later changed, after a break, to the *'News Sheet'* although the content remained the same. The *'News Sheet'* , introduced during a period when difficulty was being experienced in producing the Journal, was to become our *'Newsletter'* in 1971.

During the 1939/45 World War, the Journal continued to be published "...either monthly or bi-monthly, according to circumstances". I noted that Vol. 9, No. 3 covered the months July-December 1943. This regular entry on the back page of the Journal was subsequently amended to "...according to circumstances", although a 2-monthly interval between issues was usual.

By 1962 publication had settled down to approximately four issues per year, and continues to this day.

Southern Stars started with 16 pages and remained around this number for many years. During the 1950's 32 pages became common, with the occasional increase to 64 pages during the

early 1970s, especially following the introduction of the 2-3 day Annual Conferences which produced a considerable number of papers suitable for publication. A record issue of 216 pages was published in December 1982 with the issue of the "Proceedings of the Second New Zealand Symposium on Photoelectric Photometry".

Over the years there has been a progressive change in the Journal format, each Editor contributing his own ideas with respect to layout and content. Many articles were originally included that would now be found in the pages of the Newsletter. The variety of articles published has also broadened, reflecting the advancement of technology into the astronomical domain. However, while there may be many decades between the 1934 "Visual Star Colour" notes, and the 1982 paper on "Computer Control of Astronomcal Observing Instruments", each in its own way has contributed to the knowledge and progress of astronomy.

The regular appearance of the Society Annual Report, the often not so regular publication of Section activities, and the Obituaries, in themselves provide an interesting mini-history of the Society's fortunes.

The number of editors appointed over the half century is surprisingly small, this being undoubtedly due to the long service of Messrs. I.L. Thomsen and G.A. Eiby, who between them contributed 34 years on editorial duties.

Southern Stars editors 1934-1984:

1934-1943	I.L. Thomsen
1943-1945	M.S. Butterton
1946-1953	I.L. Thomsen
1953-1957	K.D. Adams
1957-1972	G.A. Eiby
1972-1974	J.E.C.Shearer
1974-1977	L.P. Lee
1977-1981	J.B. Mackie
1981-1982	K.D. Adams
1982-1984	G.L. Blow and R. McIntosh
1984-	A. Woodger

Finally, Vol. 1, No. 1, November 1934 opened with this editorial:

> "With this first issue of *SOUTHERN STARS*, which will, it is hoped, henceforth replace the cyclostyled Monthly Notes of the New Zealand Astronomical Society (Inc.), we hope to increase scientific interest and enthusiasm in this Dominion. A more permanent form of publishing notes, articles and results of original observations, will no doubt incite keenness on the part of our members to both receive and contribute to *SOUTHERN STARS*. This attempt to enhance the

work of the Society as a whole, will depend in part on the support of each individual member, and it is earnestly hoped that wherever possible such support will be readily given.

"Articles or notes of a kind which will have a direct appeal either to beginners or advanced workers in astronomy are needed to keep the pages of our Journal fresh. Previously the publications of the Society might have given the impression that only Directors of Section are given permission to write notes and reports. These pages are for every member, as well as the Directors, and we hope that such will be realised by our readers. To enable a greater diversity of contributors to the Journal, Directors might encourage members of their Sections to contribute notes on the observing schemes, overcoming the difficulties and results of their own personal work. Not only would this assist in adding interest to *SOUTHERN STARS* but also the Sections may find a keener faculty developing among observers. It is also hoped that the results of research work which do not contain printing difficulties in the way of mathematical equations or numerous diagrams will be recorded in this Journal instead of in overseas publications..."

The hopes and aspirations expressed in this editorial remain the same today, and the continual need to remind members that *Southern Stars* cannot exist without their contributions and support will always be with us.

Ranald McIntosh

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THE VERTICAL POTENTIAL OF THE GALAXY

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SUMMARY

The standard method of deriving the form of the gravitational potential of the galaxy from kinematic data of stars in the solar neighbourhood is described. A new technique based on phase-angles is proposed. It makes no assumptions regarding the distribution of energies of the stars so may not be very powerful. However, it is able to cope with the selection effects usually encountered in samples and this allows wide application. An illustration of the method is given.

THE PROBLEM

Our sun is in the flattened disc part of our galaxy, about ten kiloparsecs from the centre and well beyond the central bulge. The stars in the solar neighbourhood (say within 2kpc) move around the galaxy in orbits that are basically circles in the central plane but with extra in-out and up-down oscillations superimposed. The vertical motion (meaning that perpendicular to the galactic plane) appears to be uncoupled from the rest so is governed by a one-dimensional energy equation,

$$w^2/2 + V(z) = E. \qquad (1)$$

Here z is the height of a star above the central plane of the disc, V(z) the gravitational potential there, w the vertical velocity of the star and E is the star's energy per mass, which stays constant during the orbit.

From the vertical potential function, the source of the gravitation - namely the total mass density of stars, gas, dust etcetera - can be calculated. This is done via Poisson's equation, which the assumption of plane stratification simplifies to

$$\text{Total Mass Density:} \qquad \rho(z) = \frac{d^2V}{dz^2}/4\pi G. \qquad (2)$$

(G is Newton's constant of gravitation.)

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The first derivative of potential function gives the acceleration experienced by stars at various heights. More usefully, it gives the projected surface density of all the matter in the layer within $\pm z$ of the central plane.

$$\text{Projected Surface Density: } \Sigma(z) = \int_{-z}^{z} \rho(\zeta)d\zeta = \frac{dV}{dz}/4\pi G \qquad (3)$$

The observational determination of the related functions, $\rho(z)$, $\Sigma(z)$ and $V(z)$, must come from studies of the dynamics of nearby stars. In particular, values are sought for ρ_0, the total density of matter near the sun (the sun being virtually on the $z = 0$ plane), and for Σ_∞, the total projected surface density of the galactic disc.

THE STANDARD APPROACH

The usual method of attacking the problem has been through the analogy with a gravitating atmosphere. Although stars seldom encounter each other strongly enough to significantly change their motion, they nonetheless behave as molecules in a collisionful gas. The situation is described by Jeans' equations of stellar hydrodynamics. These show that the role of partial pressure of a particular gas constituent is taken, in the stellar context, by the quantity $\rho_* \sigma_*^2$, where $\rho_*(z)$ is the density at height z of a particular class of stars, and $\sigma_*^2(z)$ is the dispersion of their vertical velocities. The usual equation for hydrostatic equilibrium then translates to

$$\frac{1}{\rho_*}\frac{d}{dz}(\rho_* \sigma_*^2) = -\frac{dV}{dz} \qquad (4)$$

This formula seems the complete answer for data reduction, in that the left hand side could be observed for various species of stars to yield the same right hand side, from which the total mass density information follows via equations (2) and (3). Unfortunately, its straightforward application is precluded by the observational uncertainties in its components. In the first place, distances to stars beyond parallax range are extremely difficult to establish. Even with detailed spectrophotometry, errors up to 25% cannot be excluded, and this is without the occurrence of gross mistakes arising from mis-identification of giants and dwarfs. Star counts within limits of apparent magnitudes are relatively easy to do, but their translation to actual $\rho_*(z)$ is dubious, being notoriously susceptible to selection effects inherent in the samples but not always known. Vertical velocities, if we confine ourselves to stars near the galactic poles, may be taken to be the same as the radial velocities with a correction due to the sun's motion. These can be measured to remarkable precision. But in finding the variance of the resulting distribution of velocities and in attributing a

height dependence to it, substantial statistical errors interpose. Figures are given for the σ_*^2 of various stellar types but little information of their dependence on height is known. Added to all these uncertainties is the final one of performing numerical differentiation with respect to the poorly defined z that is implied in equation (4), so the direct approach fails.

The next step is to adopt a model for the density fall-off, and the simplest such is an isothermal atmosphere. This is equivalent to taking each σ_*^2 constant. One of the consequences of this assumption is that the overall velocity dispersion will increase with height and there is a hint of this being observed. (The reason is the same as in the atmosphere: lighter mass fractions, with higher σ_*^2 will predominate at greater heights.) Equation (4) can then be integrated to yield, for each class,

$$\rho_*(z) = \rho_*(0)e^{-(V(z) - V(0))/\sigma_*^2} \qquad (5)$$

Close to the central plane (within a few hundred parsecs), V(z) will be approximated by a quadratic. Each stellar component then has a Gaussian density profile with its own variance. Fitting observed densities and velocity dispersions to this model has been the basis of a number of studies of the solar neighbourhood, in particular Oort's, (Oort, 1932) where he determined $\rho_0 \sim .092$ solar masses per cubic parsec.

Just how much of this method's apparent efficacy depends on the strict imposition of a definite density law for the stellar components is a matter of conjecture. Certainly it conflicts with observations in giving too rapid a fall-off in density with height (the familiar meagre tail of the Gaussian curve) but whether or not this vitiates the result is difficult to say. It is to illuminate this point that we develop an alternative analysis which makes fewer assumptions.

THE PHASE ANGLE TECHNIQUE

It is proposed to derive density data from the kinematics of nearby stars by using a technique based on phase-angles.

This concept is best explained for the case of a star oscillating up and down within a uniformly dense layer, which is indeed the situation for low energy stars. Equation (2) then gives a precisely quadratic potential function so the star will execute simple harmonic motion. In the phase space, where z and w are plotted on rectangular axes, the motion of the star will be represented by a point describing an ellipse centred on the origin. By scaling the axes appropriately, this ellipse becomes a circle and the point moves around it with constant angular velocity. The angle around the circle that the point has moved through is the phase angle of the

motion at that time.

Examination of the star at random instants will show the point to be randomly placed around its circle. In other words, the probability distribution of phase-angles at random times will be uniform over the range 0° to 360°.

Moreover, supposing the star to be unobservable during part of its oscillation, say for $z < 0$ or some similar constraint in phase space, then the conditional distribution of phase-angles that can be observed will also be uniform.

The definition of phase-angles for an oscillation governed by a general potential $V(z)$ follows directly from its property of having a constant rate of increase. From equation (1), the time since crossing the central plane of a star with energy E at height z is

$$\text{Time in Orbit:} \quad t(z,E) = \int_0^z (2(E-V(\zeta)))^{-\frac{1}{2}} d\zeta \qquad (6)$$

The maximum height that the star will reach during its motion is given by the value of z at which the velocity becomes zero. Each quadrant of the oscillation takes the same time to execute, giving

$$\text{Period of Oscillation:} \quad T(E) = 4t(Z_{max},E), \text{ where } V(Z_{max}) = E. \qquad (7)$$

Hence we have the definition

$$\text{Phase-Angle:} \quad \Theta(z,E) = t(z,E) \times 360°/T(E). \qquad (8)$$

A phase-space orbit for a general potential will not be a precise ellipse so the phase-angle will not be so readily identified geometrically. However, defined as it is in equations (6), (7) and (8), it will increase uniformly throughout the orbit and hence have a uniform probability distribution over random times.

Now envisage an assembly of stars with different energies and different phase-angles. The composite phase-space would show their representative points moving on paths which are roughly concentric ellipses of sizes dependent upon the energies. Also the rate of moving around the paths depends on energy, so very quickly a spread of phase-angles would develop. The process is called phase-mixing. A snapshot taken of this melee would reveal a uniform spread of phase-angles, even if they all started out together, providing time enough has elapsed to allow all the points a few circuits.

Here then is the germ of a possible method to determine if a particular choice of potential is statistically consistent with observations:

1. Observe z_i, w_i for a number of stars.

2. Calculate Θ_i for the given V(z).

3. Test the hypothesis that the Θ_i arise from a uniform probability distribution.

It is clear that in its raw form, this test demands a sample of stars which are free from kinematic selection. Beyond that there are no restrictions, for instance stars of differing masses (which would have to be treated separately by the standard method) can be combined. Also, no assumptions regarding the sample's distribution of energies is imposed.

A major factor in favour of this method is that the formulae can be readily enhanced to cope with geometrical selection effects of the type alluded to above. A common observational procedure is to look at all stars of a certain spectral type within a certain angle from the galactic pole; that is, a cone. The fact that a greater area of the galaxy is sampled as height increases is allowed for by including a factor ζ^2 in the integrand of (6). The resulting pseudo-times and pseudo-angles then have the required property of conditional uniformity. Also, stars with energies so large that their orbits would carry them beyond the greatest height at which they are observable are conventionally ignored but can be included here merely by stopping the integrals at the maximum observable height.

A useful by-product of the method is that it allows, in principle, the actual distribution of energies in the sample to be determined. Thus a check on the standard method where this is a prescribed input can be made.

AN ILLUSTRATIVE APPLICATION

Derek Jones of The Royal Greenwich Observatory has determined heights and vertical velocities of 50 M stars in the Henry Draper Catalogue, brighter than $10^B.0$ (blue magnitudes) and within 17½° of the South Galactic Pole (Jones, private communication). The observations were made from Mount Stromlo. The angular selection is strict, so we are dealing with a cone. In contradistinction, the height limitation is very fuzzy because of the intrinsic spread of absolute luminosity amongst M stars. It seems wise to rely on completeness of the sample only up to 1200 parsecs, leaving 46 stars.

A family of potential functions V(z) with two parameters ρ_0 and Σ_∞ and with sensible limiting behaviour was adopted. (Details of this choice, which allows convenient evaluation of the integral (6) will appear elsewhere.) For various values of ρ_0 and Σ_∞, the pseudo-angles Θ_i (i=1 to 46) were computed. This distribution of these on 0° -180° was found.

To measure the deviation of the observed distribution from uniform the Kolmogorov-Smirnov statistic was used. This is a non-parametric test based on the maximum difference between the observed cumulative probability function and the theoretical one. A value can then be attached to the choice of ρ_0 and Σ_∞ giving the probability that the resulting phase angles could indeed have come from a uniform distribution. These are given as percentages in the following table.

Σ_∞	50	60	70	80	90	100	110	120	130	140	150 $M_\odot/pc^2$
ρ_0											
.05	39	44	47	49	48	48	47	47	47	46	47
.06	30	43	53	57	47	47	48	51	53	54	53
.07	46	43	46	62	48	51	51	49	48	47	46
.08	41	35	45	60	55	50	46	45	43	42	41
.09	26	30	32	41	53	48	44	41	39	38	37
.10	26	22	28	38	50	47	43	40	37	35	34
.11	24	21	26	22	32	44	41	39	36	34	32
.12	37	16	18	21	30	40	39	37	35	33	31
.13	36	16	18	20	17	29	37	35	33	31	30
.14	34	19	11	16	17	20	35	33	31	29	28
.15	35	26	11	16	13	18	32	31	29	28	26
$M_\odot/pc^3$											

The best fit for the parameters is where the tabulated probability is highest. This occurs at $\rho_0 = .07\ m_\odot/pc^3$, $\Sigma_\infty = 80\ m_\odot/pc^2$, but the surface is very lumpy so little significance can be accorded these values. In fact, other computer runs show that the positions of the peaks are rather sensitive to the choice of the height cut-off. Also, the absence of stars above 1200pc means that nothing is known about the mass in the regions beyond (the "galactic halo") and this results in high ridges appearing in the probability surface at ever larger values of Σ_∞. Presumably, a sample of many more stars extending further out of the galactic plane and with more accurately defined completeness, would give a smoother, more robust maximum.

CONCLUSION

The phase-angle approach offers a new way of reducing kinematic data of stars to give parameters of the galactic gravitational field. By not assuming particular models for the densities of the various stellar components it loses some of the power of standard methods. However, it gains in being able to include selection effects inherent in samples.

ACKNOWLEDGEMENTS

I thank Dr. Derek Jones for raising the problem and providing hard-won data. I also thank Professor Donald Lynden-Bell of the Cambridge Observatories for helpful discussions on the solution and for providing the facilities to apply it.

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ELECTROPHONIC METEOR FIREBALLS

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(Presented at the 1984 Annual Conference of the Royal Astronomical Society of New Zealand)

ABSTRACT

There is a long history of occasions when witnesses of very bright (-12 mag) meteor fireballs have reported hearing "swishing" or "buzzing" sounds concurrently with their visual observation. For 200 years such anomalous sounds have been unexplained, being most often dismissed by meteor astronomers as psychological illusions.

A very large fireball estimated to be of -16 mag passed over Sydney and Newcastle, N.S.W., in the early morning of 1978 April 7, giving rise to many completely independent reports of anomalous sounds. An extensive study of the phenomenon has led to an explanation in terms of Very Low Frequency (VLF) electromagnetic (EM) radiation generated by the turbulent ionised wake of the fireball, with subsequent transduction of the EM energy into acoustic form by suitable objects in the close vicinity of the observer.

Recent Russian studies support this mechanism, but confirmation of the VLF signature of large fireballs is still awaited. The rarity and unpredictability of such events makes such confirmation very difficult. It seems likely that similar sounds reported during intense auroral displays result from EM energy transmitted and transduced in a similar way.

INTRODUCTION

It is a rare privilege these days for a scientist to have an opportunity to solve a mystery which has baffled investigators for two centuries. This year marks the 200th anniversary of a paper published by Sir Charles Blagdon (1784), Secretary of the Royal Society of London, in which he discussed many observations of a large meteor fireball which passed over South East England in 1783. The large number of

reports of sounds heard simultaneously with the sighting by observers 100km or more from the ground track of the fireball, perplexed Sir Charles and led him to state that he "would leave it as a point to be cleared up by future observers". These were wise words indeed because it was a further century before electromagnetic waves were first produced and identified. And almost another century had to pass before a further large fireball provided the incentive for me to seek a physically tenable explanation.

Extensive summaries of reports of anomalous sounds generated by meteor fireballs appear in review papers by La Paz (1958) and by Romig and Lamar (1963) together with inconclusive attempts at presenting a physical explanation. Failures to explain this elusive phenomenon have led meteor physicists and astronomers to disregard it and dismiss all reports as a purely pscyhological reaction to the startling appearance of the fireball. As recently as 1979 "Meteore", the newsletter of the IAU Congress in Montreal, asked "Or is this a more fruitful field for psychologists rather than physicists?" However the psychological explanations were questioned long ago by Udden (1917), whose detailed study of a large fireball observed in Texas led him to ask if the sounds could be electrical in origin.

1978 FIREBALL OBSERVATIONS

A real breakthrough in solving this "Riddle of the Sounds" had to wait until a very large fireball passed over New South Wales at 0444h AEST on 1978 April 7 (refer Keay, 1980a, for full details of the fireball, its trajectory and orbit). Its brilliance was estimated to be -16 mag. and it was seen by hundreds of early risers. Thirty first-hand reports were gathered and ten of these included descriptions of unusual sounds coincident with the occurrence of the fireball. My first reaction was to invoke the standard psychological pseudo-explanation, but the completely independent and thoroughly veracious testimony of those who heard the simultaneous sounds convinced me of their reality, just as Udden became so impressed 60 years previously. In three of the ten cases the sounds preceded the visual identification of the fireball, which rather foils any psychological hypothesis.

Strength of conviction is no substitute for scientific method. However all attempts to discover an electromagnetic signature of the fireball failed: there were no reports of radio interference, blackouts, fading or other abnormalities at the time of the fireball. This is quite usual for even the very largest fireballs. Clearly, therefore, the energy radiated from the fireball must lie in a poorly monitored region of the EM spectrum, if EM radiation is responsible for the anomalous sound generation.

SPECTRUM AND ENERGY CONSIDERATIONS

Apart from emissions in and near the optical region of the EM spectrum, no EM radiation has ever been recorded from any meteor fireball (Keay 1980b). But records are very sparse for frequencies between 3Hz and 300kHz (which will be loosely described as the Very Low Frequency or VLF region of the spectrum). Since large meteor fireballs are rare events, it is considered likely that their signature on VLF records has not yet been identified.

There is abundant energy released during the deceleration of a large meteoroidal mass when it enters the atmosphere. For masses of the order of tonnes, typical for large fireballs, the peak power levels are in the order of thousands of gigawatts. Some 90-95 percent of the energy is dissipated in an intense shock wave which causes sonic booms and rumbles to be heard up to a minute or two after the visual sighting. About one percent of the energy is radiated as light and heat. Recently, due largely to the work of ReVelle (1979), it has been recognised that much of the remaining five percent or so is lost in the creation of turbulent eddies in the wake of the fireball whenever it penetrates the atmosphere to an altitude below 20 to 70 km depending on its size and speed.

EM GENERATION MECHANISM

Several mechanisms have been proposed for the generation of radio frequency emissions from nuclear explosions (e.g. Karzas and Latter, 1962) but the apparent lack of such emissions from meteors has inhibited theoretical investigations of likely mechanisms. The nuclear explosion mechanisms are for the most part inapplicable to meteor fireballs, but they did suggest that entrapment of the geomagnetic field by the highly ionised plasma in the fireball wake was a likely possibility.

Calculations of the ratio of the geomagnetic energy density and energy of turbulence; the timescale for the formation of turbulent eddies compared with the field penetration time; and the magnetic Reynolds number which is a necessary condition for control of the magnetic field by the plasma in the eddies; all support a mechanism proposed by Keay (1980b) in which the magnetic field is twisted into a "magnetic spaghetti" which radiates VLF EM noise as it relaxes when the controlling plasma recombines. This mechanism has now been supported by calculations made by Bronshten (1983a,b).

Wake turbulence only occurs for very large fireballs brighter than -12 mag , which are the only ones found to produce electrophonic sounds.

PERCEPTION OF ELECTROPHONIC SOUNDS

Previous attempts to explain anomalous sounds from meteor fireballs have always failed to provide a credible reception mechanism. If EM radiation was postulated, its detection was thought to be through rectification of the signal by the presence of non-linear conduction effects in or close to the observer. Identification of such signal detectors has always been lacking.

For the reception of EM radiation in the VLF region no signal rectification is necessary. As long as such signals lie within the frequency range for human audibility, a transduction process is all that is required. This is inherently simpler to achieve by mundane objects and the conversion efficiency is bound to be higher because frequency conversion is not involved.

Most objects which move or deflect under the influence of an electrostatic field can be made to vibrate at their natural frequencies by periodic electric fields, and hence behave much as an electrostatic loudspeaker. Human hair is a typical example: in laboratory tests subjects with ample loose hair appeared to have lower thresholds for the perception of electrophonic sounds (Keay, 1980c). This alone may explain why some individuals report anomalous sounds from bright meteor fireballs while other observers standing close by hear nothing.

EXPERIMENTAL VERIFICATION

Further laboratory work on the perception of electrophonic sounds is clearly desirable, but such experimentation is not easy to carry out. The extremely low acoustic levels demand the use of a well designed anechoic chamber and very sensitive instrumentition.

Verification of the generation mechanism calls for two main efforts: the development of a rigorous theoretical treatment of the "magnetic spaghetti" concept; and the positive identification of the VLF signals emitted by the larger fireballs. An appeal for a listing of electrophonic fireballs was made when I published the VLF hypothesis (Keay, 1980b).

Bronshten in the Soviet Union has responded to the need for a comprehensive catalogue to facilitate correlation with VLF records. He hopes to have a catalogue spanning the past 20 years (since 1962 when earlier catalogues were abandoned) ready early in 1984 (Bronshten, 1983a). In the meantime, the monthly bulletins of the Scientific Event Alert Network (SEAN) based at the Smithsonian Museum in Washington, D.C., are reporting an increasing number of electrophonic fireball

events: thirteen between November 1982 and March this year (1984) as shown in Table 1.

Even so, global coverage is still very patchy, as may be gathered from Table 1 where nine of the thirteen observations were made from the U.S.A. An effort is underway to extend the reporting of fireball events by airline flight crews. While reports of electrophonic sounds by airline crews are not expected due to the high ambient noise level on the flight deck, precise knowledge of the time of occurrence of a fireball will aid the recognition of its signature on VLF records.

CONCLUSION

Although the hypothesis that VLF EM radiation from meteor fireballs is responsible for reports of anomalous sounds, it remains unproven four years after publication. This simply reflects the difficulty of experimentally reproducing weak physical effects and in correlating diverse records of transient events which are, after all, fairly rare and usually poorly reported.

The same general comments apply to the electrophonic sounds occasionally heard during intense auroral displays, but which have been widely discounted by the majority of auroral scientists (who have invariably never experienced such sounds at first hand).

Hopefully this situation for anomalous fireball and auroral sounds will not persist and a definite result will emerge from the current assault on the problem. If the VLF hypothesis is vindicated, the Riddle of the Sounds may be solved.

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TABLE 1 Reported Electrophonic Fireball Times and Locations 1982 - 1984

1982 Nov 9	0210 GMT	NW Oregon, USA	46-47 N	123 W
1982 Nov 9	0214 GMT	Connecticut, USA	41-42 N	72-73 W
1983 Jan 16	0045 GMT	East England	51-52 N	1-2 E
1983 Mar 18	1508 GMT	West Australia	32-35 S	116-118 E
1983 Apr 2	0347 GMT	Pennsylvania, USA	41-42 N	75-76 W
1983 Apr 3	0428 GMT	California, USA	34-36 N	115-121 W
1983 May 3	0230 GMT	Georgia, USA	33-34 N	84-85 W
1983 Jul 19	2100 GMT	West Portugal	37-39 N	6-9 W
1983 Oct 27	1735 GMT	Central Europe	49-50 N	12-14 E
1983 Nov 26	0730 GMT	Carolinas, USA	33-37 N	78-85 W
1984 Jan 7	1020 GMT	Florida, USA	27-29 N	80-83 W
1984 Jan 9	0140 GMT	Central USA/Canada	46-50 N	93-97 W
1984 Mar 21	0415 GMT	Oregon, USA	43-44 N	120-121 W

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WILLIAM HUGGINS AND ASTRONOMICAL SPECTROSCOPY

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It is well known that Joseph Fraunhofer in about 1815 and again in 1823 was the first to observe the spectra of stars. He found absorption lines in the spectrum of Sirius which seemed to differ markedly from lines in the solar spectrum which he had first catalogued. It is perhaps an indication of how far Fraunhofer was ahead of his contemporaries when we find no significant observations of stellar spectra reported until 1863, an interval of about four decades†.

Strangely, in about that year, four astronomers almost simultaneously recommenced the science of stellar spectroscopy. Possibly Lewis Rutherfurd in New York may have been the first. Angelo Secchi at the Collegio Romano and George Biddell Airy at the Royal Greenwich Observatory were two others who turned the spectroscope to the heavens at this time. But the achievements of William Huggins at his private observatory in Tulse Hill, London were perhaps the most remarkable of these early pioneers. Whereas the work of both Rutherfurd and Airy was fairly brief in this new field, Secchi and Huggins pursued stellar spectroscopy with considerable vigour. With Secchi's death in 1878 Huggins was the undisputed master of stellar spectroscopy; he was an active researcher for nearly half a century. Huggins had interests that were wide-ranging. His approach to the new science was always refreshingly innovative, especially for an amateur, and his published papers, because of their clarity of expression, are still a delight to read.

Huggins had installed an 8-inch Alvan Clark refractor at his observatory in London and it is with this instrument that he began observing the spectra of the stars in December 1862. The early observations were all visual and achieved by passing the star light through a 2-prism flint glass spectroscope mounted at the eyepiece end of the telescope. This work was also only a few years after Kirchoff and Bunsen in Heidelberg had interpreted the dark Fraunhofer lines in the solar spectrum as being due to the same chemical elements that produce bright spectral lines when introduced into a flame in the laboratory. The influence of Kirchoff was readily acknowledged. The challenge for Huggins in 1862 was to

† *Brief observations of stellar spectra were described by Müller in Munich in 1838 and by Donati in Rome in 1860.*

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undertake the same for the stars as Kirchoff had achieved in the spectral analysis of the sun. Much later in his career Huggins reflected on the circumstances in which he took up astronomical spectroscopy: 'I soon became a little dissatisfied with the routine character of ordinary astronomical work, and in a vague way sought about in my mind for the possibility of research upon the heavens in a new direction or by new methods. It was just this time, when a vague longing after newer methods of observation for attacking many of the problems of the heavenly bodies filled my mind, that the news reached me of Kirchoff's great discovery of the true nature and chemical composition of the sun from his interpretation of the Fraunhofer lines.

'This news was to me like the coming upon a spring of water in a dry and thirsty land. Here at last pesented itself the very order of work for which in an indefinite way I was looking - namely to extend his novel methods of research upon the sun to the other heavenly bodies.' (Huggins, 1897).

In his early work he was assisted by Prof. William Allen Miller, chemistry professor at the University of London. No doubt partly because of Miller's influence, the early work was in astro-chemistry. Huggins and Miller were able to compare the spectra of the stars simultaneously with the spark spectra of 29 different metals. An extensive account of this work appeared in the Philosophical Transactions of the Royal Society in 1864 (Huggins and Miller, 1864). The absorption lines in the spectra of nearly fifty stars were described, with three or four bright stars being observed in considerable detail. For Aldebaran, Betelgeuse and β Pegasi, for example, positions for about 70 lines were measured and several elements in these stars, including sodium, magnesium, hydrogen, calcium and iron were identified.

Huggins later commented on this work: 'The important object of this original spectroscopic investigation of the light of the stars and other celestial bodies, namely to discover whether the same chemical elements as those of our earth are present throughout the universe, was most satisfactorily settled in the affirmative; a common chemistry, it was shown, exists throughout the universe'. (Huggins, 1909).

The significance of this early work was clearly not lost on Huggins and Miller when they concluded their monumental paper of 1864 with a comment on the elements needed for living organisms: 'It is remarkable that the elements most widely diffused through the host of stars are some of those most closely connected with the constitution of the living organisms of our globe, including hydrogen, sodium, magnesium and iron...These forms of elementary matter, when influenced by heat, light and chemical force, all of which we have certain knowledge are radiated from the stars, afford some of the most important conditions which we know to be indispensible to the existence of living organisms such as

those with which we are acquainted'. (Huggins and Miller, 1864). It seems that Darwin's 'Origin of Species', published in 1859, was influencing even the astronomical literature of that time.

In August 1864 Huggins turned his attention to the nature of the nebulae. These fuzzy patches of faint light in the sky were widely held to be composed of unresolved stars, in which case their spectra would be essentially stellar, that is with absorption lines. In his first paper on this subject he found eight nebulae with bright lines in emission, quite unlike the spectrum of any other known type of celestial object. (Huggins and Miller, 1864). The bright lines included those of hydrogen gas and also an intense pair of green lines which Huggins at first believed to be due to nitrogen. Later careful measurement of their wavelengths meant he had to abandon this idea. (Huggins and Huggins, 1889). They were ascribed to a strange new element 'nebulium' and were never observed in the spectra of laboratory sources. Only in the 1920s did Ira Bowen solve the mystery of nebulium when he showed it was none other than ionised oxygen shining under conditions of very low density.

Huggins and Miller however correctly concluded in their first discussion of the bright-lined nebulae that these objects 'must be regarded as enormous masses of luminous gas or vapour', which would therefore never be resolved into stars using larger telescopes. The gaseous nature of the nebulae could be deduced, since a hot gas as in a flame or discharge tube in the laboratory also gave a spectrum of bright lines.

Having thus pioneered in the first work in stellar chemistry and nebular spectroscopy, Huggins was now fortunate to be able to record another first in 1866. This year a new star or nova appeared in May in the constellation of Corona Borealis. It was first seen from Ireland on May 12 and Huggins heard the news by the 16th when it was as bright as second magnitude. He observed it spectroscopically with Miller, the last time the two worked together. (Huggins, 1866). T Coronae Borealis thus became the first nova to be studied with the spectroscope. The visible spectrum showed five bright emission lines including three due to hydrogen. In addition there were a number of absorption lines, including the well-known orange pair due to sodium. T Coronae was the first of a rather heterogeneous and rare group of emission line stars, to which Secchi in Rome added the famous objects β Lyrae and γ Cassiopeiae in that same year. Meanwhile the nova was fading rapidly, and by the beginning of June 1866 was already down to ninth magnitude and no longer observable spectroscopically.

The early 1870s were fortunate years for William Huggins. The Royal Society of London had received £1,350 from the Oliveira bequest, and this sum was used to construct a 15-inch refractor and an 18-inch reflector, to be interchangeable on a single mount. These telescopes were erected at Tulse Hill on

indefinite loan to Mr. Huggins. The whole installation was completed by February 1871 and housed in a new 18-foot diameter dome.

Earlier Huggins had reported the first attempt to measure a stellar radial velocity, or motion in the line of sight, using the minute shift of wavelength of stellar spectral lines by the Doppler effect. This first attempt had been in 1868 for Sirius when he compared the positions of the dark hydrogen Hβ line in the spectrum of Sirius with the same line appearing in emission from a hydrogen discharge tube. (Huggins, 1868). He wrote at that time: 'I am certain that the narrow line of hydrogen, though it appeared projected upon the dark line of Sirius, did not coincide with the middle of the line, but crossed it at a distance from the middle...apparently equal to about one-third or one-fourth of the interval separating the components of the double line D'. The shift of just over one Ångstrom unit was interpreted as a recession of 41.4 miles per second from the earth. After allowing for the earth's orbital motion, this became 29.4 miles per second relative to the Sun. (Huggins, 1868).

This radial velocity work required painstaking care, and Huggins reembarked on this research in 1872 with the new 15-inch telescope. He presented results for thirty stars that year to the Royal Society. (Huggins, 1872). Sirius was now measured at a recession of about 18 to 22 miles per second and the error bars were considerable, reflecting the difficulty of determining visually the very small line displacements in spectra at the telescope. When compared with a modern value of Sirius' motion (-8km/s or an approach of 5 miles per second) we see that Huggins was in error both in amount and direction. However he pioneered in the application of the Doppler principle to the motions of the stars. Only later when Hermann Carl Vogel undertook this work photographically at Potsdam in Germany from 1888, were the first really reliable results obtained.

The mention of stellar spectrum photography brings us to another of the great achievements of William Huggins. In 1863 he and Miller had been the first to attempt to record stellar spectra on the old wet collodion plates that were then available. (Huggins, 1864). These early tests were unsuccessful, and no absorption lines were recorded. Then in 1872 Henry Draper, another amateur astronomer at his private observatory in the state of New York, first successfully photographed the spectrum of a star, Vega.

This work was soon taken up again by Huggins, (Huggins, 1877), assisted now by Mrs. Huggins whom he had married in 1875. Using the new dry plates in which the silver bromide salts were suspended in a gelatine emulsion, Huggins and his wife recorded the spectra of Sirius, Vega, Altair, Spica, Deneb, Arcturus, Rigel, Betelgeuse, Aldebaran, Capella and η Ursae Majoris in the blue and near ultraviolet. (Huggins, 1880). For this work they observed with the new 18-inch

reflector equipped with a spectrograph using quartz lenses and an Iceland spar prism for the ultraviolet region of the spectrum.

With this instrument at first seven, (Huggins, 1877), later twelve, (Huggins, 1880), strong lines were photographed in Vega and other white stars, most of them invisible to the eye in the ultraviolet. He speculated that these new lines were probably due to hydrogen, a result confirmed from laboratory studies in Berlin at about the same time. In his first paper in 1877 on the ultraviolet spectro-photography of Vega he noted: 'The photograph shows seven strong lines, all of them slightly shaded at the sides. The two lines which are least refrangible coincide with two known lines of hydrogen in the solar spectrum'. (Huggins, 1877).

In 1896 Huggins was already an old man, but his research continued unabated. In that year he built a new ultraviolet spectrograph for the Tulse Hill reflector. This instrument was mounted at the cassegrain focus and made use of two Iceland spar prisms and quartz lenses. With this instrument Sir William Huggins (he was knighted in 1877) undertook one of his last great works, the production of 'An Atlas of Representative Stellar Spectra', being volume I of the Publications of the Sir Wm. Huggins Observatory, published in 1899. (Huggins and Huggins, 1899). The magnificent photographic spectra of the brighter stars in the ultraviolet and blue regions were here presented in a sequence of spectral characteristics that Huggins believed to be an evolutionary progression, but which was later, following the work of Saha in 1921, shown to be none other than a temperature sequence.

For many astronomers, Sir William Huggins is regarded as the founder of stellar spectroscopy. He came to studying stellar spectra in his thirty-eighth year. When he died in 1910 he had completed nearly half a century of pioneering research in this field. The discoveries of this illustrious amateur in astrochemistry captured the popular imagination of the day and his name is still regarded with high esteem a century later. The value of Huggins' research was fully recognised in his lifetime, as the awards of F.R.S. (1865), K.C.B. (1877) and the O.M. (one of the twelve original members) (1902) testify. Huggins had no institutional affiliation, but he gave loyal service to both the Royal Astronomical Society and especially to the Royal Society, and became president of both these bodies at different times. The two Royal Society telescopes were returned to the society in 1908, and they were then presented to the University of Cambridge and erected there before Huggins' death in 1910. Lady Huggins survived Sir William by five years.

Of the earlier pioneers in stellar spectroscopy during the second half of the last century, names that included Rutherfurd and Draper in New York, Secchi in Rome, Vogel and his coleagues at Potsdam, Wolf and Rayet in Paris, Lockyer and

Huggins in London, I find that I admire Huggins the most. The reasons are nicely summarised by Huggins' contemporary at Greenwich, E.W. Maunder: 'In almost every department of the physical study of the heavenly bodies, Huggins either led the way, or was one of the earliest and most resourceful workers, so that R.A. Proctor was justified in applying to him the title of the "Herschel of the Spectroscope". For just as Sir William Herschel...used (the telescope)...to ascertain the structure of the sidereal universe, so in his turn Huggins, who neither invented the spectroscope nor was the first to use it in astronomy, yet stamped his name and impress on almost every department of research to which it was directed'. (Maunder, 1913).

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SOME HISTORICAL OBSERVATIONS OF THE NEBULAE II HERSCHEL TO PHOTOGRAPHY

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The first paper in this series described observations of the nebulae made firstly with the naked eye and later with the fledgling telescope from earliest times up to the time of Messier who compiled perhaps the best known catalogue of nebulae. This paper begins with the, still visual, observations of William Herschel and traces the progress made in investigating the nature and structure of the nebulae through the nineteenth century including the rapid advances made following the introduction of the spectroscope and the photographic plate.

In the year following the publication of Charles Messier's list of 103 nebulae, William Herschel began his observations of the skies using large reflecting telescopes. Within three years, in 1786, he published the first results of this work in the Philosophical Transactions of the Royal Society of London. The paper was entitled "Catalogue of One Thousand New Nebulae and Clusters of Stars" and had the following introduction:

> *The following catalogue which contains one thousand new Nebulae and Clusters of Stars is extracted from a series of observations (or Sweeps of the Heavens) which was begun in the year 1783, and which I am still continuing till the whole be completed...The telescope I have used...is a Newtonian reflector of 20 feet focal length, and 18 7/10 inches aperture. The sweeping power has been 157, except where another is expressly mentioned. The field of view 15'4". My eyepiece is mounted on that side of an octagon tube, which, in the horizontal position of the instrument makes an angle of 45° with the vertical.*

The first observing method Herschel used he described thus:

> *...to suffer the telescope to hang freely in the centre; then walking backwards and forwards on the moveable gallery, I drew the instrument from that position by a handle fastened to a place near the*

> *eye-glass, so as to make it follow me, and perform a kind of very slow oscillation at 12 or 14 degrees in breadth, each taking up generally from 4 to 5 minutes of time. At the end of each oscillation I made a short memorandum of the objects I chanced to see, and when a new nebula or cluster of stars came in my way, I made a delineation of the stars in the field of view, both of the finder and of the telescope, that it might serve me to find them again. This being done, the instrument was, by means of a fine motion under my hands, either lowered or raised about 8 or 10 minutes, and another oscillation was then performed like the first.*

Entries in the catalogue took the following form; a class description, when observed, a nearby bright reference star, position of the object relative to that star, and the number of times observed. A typical entry being:

Class	*First Observed*	*Reference Stars*	*Preceding or Following*	*Distance from Reference Star*			*No. of Observations*
				Hour Angle	*North or South*	*Declination*	
IV-26	*1785 Feb 1*	*34(γ)Erid*	*f*	*16m16s*	*N*	*0°49'*	*2*

Description

vB perfectly R or vl. elliptical, planetary but ill defined disk. 2d obs.r. on the borders and is probably a very compressed cluster of stars at an immense distance.

A modern translation of the "Description" would be "a very bright round planetary nebula north east of the star γ Eri".

In the space of some twenty years Herschel discovered and catalogued over 2,500 nebulae and star clusters which he divided into eight separate classes: I bright nebulae, II faint nebulae, III very faint nebulae, IV planetary nebulae, V very large nebulae, VI very compressed and rich clusters of stars, VII compressed clusters of stars and VIII loosely scattered clusters of stars.

Whilst Herschel's main work with the nebulae was cataloging them, he did speculate as to their nature and concluded that there were two types: star clusters composed of individual stars, and nebulae composed of "shining fluid". In the early part of his career Sir William's successor as an observer of the nebulae, Sir John Herschel, his son, also held these views.

Sir John Hershel's first major observing programme was to re-observe all the objects catalogued by his father in the Northern Hemisphere using an 18¼ inch clear aperture telescope of 20 foot focal length. This gave him the required skill

both as an observer and as an instrumentalist (in those days he regularly repolished and refigured the speculum mirror of the telescope) needed before commencing his own major observing programme, that of cataloging the nebulae in the Southern Hemisphere. In Sir John's own words:

> *I resolved to attempt the completion of a survey of the whole surface of the heavens, and for this purpose to transport into the other hemisphere the same instrument which had been employed in this, so as to give a unity to the results of both portions of the survey, and to render them comparable with each other.*

The telescope was sited at Feldhuysen then about 10km from Cape Town in the direction of Wynberg on the eastern slopes of Table Mountain. The observations made by Sir John, both in England and South Africa, resulted in a large number of new discoveries which formed part of his 1864 catalogue of all known clusters and nebulae, amounting in all to 5,079 objects. The following description was taken from notes made by Sir John when he was actually observing the region containing the Small Magellanic Cloud (then more commonly called the Nebecula Minor).

> *Sweep 482 - Zone 162° - 165° August 12, 1834*
>
> *23h 19m Began. The ground of the sky very decidedly but not very richly dotted rather than "stippled" with faint stars. Stars of 9, 10, 11, 12 magnitudes are sparingly scattered over it.*
>
> *0h 2m The lesser nebecula is now approaching, but I discern no indications in the field throughout the zone which should lead to expect any remarkable object. On the contrary, the stippled or dotted appearance mentioned at 23h 19m is gone and the ground is black.*
>
> *0h 13m 6.5s 163°5'55" There is now a great increase of st.13m in the field. On further examination they appear to be outliers of the great globular cluster (47 Touc)... This cluster is completely insulated. After it has passed, the ground of the sky is completely black throughout the whole breadth of the sweep.*
>
> *0h 29m 7.3s The field begins to show more stars and to be alive.*
>
> *0h 37m 5.1s We are now in the cloud. The field begins to be full of light, perfectly irresolvable.*
>
> *0h 46m 3.7s 164°19'23" I should consder about this place to be the body of the cloud which is here fairly resolved into excessively minute stars, which, however*

are certainly seen with the left eye.

1h 9m 50.2s Re-examined by the side motion the whole cloud in detail and in general. The main body is resolved, but barely. I see the stars with the left eye. It is not like the stippled ground of the sky. The borders fade away quite insensibly and are less or not at all resolved. The body of the cloud does not congregate much into knots, and altogether it is no way a striking object, apart from the nebula and clusters.
N.B. Mirror a good deal tarnished - at least a fourth of its light.

An enlarged revised edition of the Herschel Catalogue was produced by John Dreyer, a Dane working at the Armagh Observatory in Ireland, which brought the total number of known clusters and nebulae to over 10,000 and marked the end of the production of major catalogues from purely visual observations. Dreyer's catalogue was, of course, the New General Catalogue or NGC.

With the completion of J. Herschel's General Catalogue more interest began to be shown in the composition of the nebulae. Were there two ditinct classes, star clusters and "shining fluid", or given a sufficiently large telescope, would even the shining fluid be resolved into myriads of faint stars? William Parsons, third Earl of Rosse, believed he had solved the problem using his six foot reflecting telescope with which he commenced observing the nebulae in 1845. In addition to this large instrument Lord Rosse also possessed a smaller three foot telescope which, he noted, gave better results when newly polished than did the larger instrument if its mirror were in need of polishing as indeed he recorded in his observations of M42 (the Great Nebula in Orion) made on 22 February 1862:

3 feet speculum newly polished shows it much better than the former, indeed better than the 6 feet now in the tube. The part round the trapezium looks just like fine flour scattered over a grey surface, so that I have no hesitation in saying that it is composed of stars, many small ones seen through it.

Whilst Lord Rosse was mistaken in his interpretation of his observations of M42, that was not the case with his discovery of the spiral nature of some nebulae. He reported his observations in the Philosophical Transactions of the Royal Society in 1850:

H1622 (M51) - This object has been observed twenty eight times with the 6 feet instrument; it had been repeatedly observed previously with the 3 feet instrument. September 18, 1843 - Observed with the 3 feet instrument; single power lens, 1-inch focus; a great many stars clearly visible in it, still

> *Herschel's rings not apparent, at least no such uniformity as he represents in his drawing.*
>
> *April 11, 1848 - 6 feet instrument. Saw the spirality of the principal nucleus very plainly; saw also spiral arrangement in the smaller nucleus.*

Lord Rosse compared his observations with those of Messier and the Herschels before him and noted that more and more detail was seen with increasing optical power which he believed supported the hypothesis that, given a big enough telescope, all nebulae would eventually be resolved into stars. That the Earl's work was held in high esteem by contemporary astronomers is testified to by Admiral Smyth's eulogy in his book "Speculum Hartwellianum" published in 1860:

> *In a word, the discovery of SPIRAL NEBULAE, the most the most extraordinary and unexpected class of objects which modern research has yet disclosed in stellar astronomy, is wholly due to the noble Earl: and their forms are so entirely removed from all analogy with the phenomena presented either in the bodies of the solar system, or the whirl's of Encke's comet, in the star curves I found in 35 Messier, or in the stellar strata of Padre Secchi, that notions as to their physical condition were merely guess-work. The enigma is another unequivocal mark of the illimitable power of the SUPREME CREATOR!*

There was however opposition to the notion of spiral structure in the nebulae as is revealed in Smyth's footnote to the above!

> *The spirality of nebulae has been strangely suggested to be owing to scratches on the metallic mirror used: but I hope this notion is abandoned, since it is utterly untenable either upon optical or mechanical grounds.*

Lord Rosse was not the only observer who claimed to have resolved the Great Nebula in Orion into stars as a similar claim was made by Bond using the fifteen inch refracting telescope at Harvard and, in 1854, Olmsted felt sufficiently confident to declare that these observations effectively demolished Herschel's ideas of two different types of nebulae. This confidence was untimely as only ten years later on 29 August 1884 William Huggins used a spectroscope on a bright planetary nebula in Draco. He saw at once, that unlike stars which had a continuous spectrum crossed by dark absorption lines, the spectrum of the nebula was one of bright discrete emission lines due to a mass of glowing gas. By measuring the wavelength of the lines, he was able to deduce that some were due to hydrogen and some to a then unknown element he named "nebulium". In Huggins' own words:

> *I directed the telescope (an 8 inch Clark refractor) armed with the spectrum apparatus to this nebula. At first I suspected some derangement of the instrument had taken place; for no spectrum was seen, but only a short line of light perpendicular to the direction of dispersion. I then found that the light of this nebula unlike any other ex-terrestrial light which had yet been subjected by me to prismatic analysis, was not composed of light of different refrangibilities, and therefore could not form a spectrum. A great part of the light from this nebula is monochromatic, and after passing through the prisms remains concentrated in a bright line occupying in the instrument the position of that part of the spectrum to which its light corresponds in refrangibility.*

By 1868 Huggins had observed spectroscopically over 70 nebulae of which more than one third showed an emission spectrum including the Great Nebula in Orion. Huggins drew the following conclusions from his observations of the emission line nebulae:

> *It is obvious that the nebulae can no longer be regarded as aggregations of suns after the order to which our own sun and the fixed stars belong. We have in these objects to do no longer with a special modifification only of our own type of suns, but find ourselves in the presence of objects possessing a distinct and peculiar plan of structure. In place of an incandescent solid or liquid body transmitting light of all refrangibilities through an atmosphere which intercepts by absorption a certain number of them, such as our sun appears to be, we must probably regard these objects, or at least their photo-surface, as enormous masses of luminous gas or vapour.*

So William Herschel's hypothesis that some nebulae were unresolved star clusters and some clouds of shining fluid was eventually proved by using a spectroscope though the 'recording medium' was still the human eye.

The next advance in the study of the nebulae was the application of the then relatively new science of photography. In 1880 Henry Draper obtained the first photograph of the Great Nebula in Orion. He sent a copy of the photograph to Mr. Ranyard who in turn presented it to a meeting of the Royal Astronomical Society held in London on Friday 14 January 1881. A lively discussion ensued:

> *Mr. Ranyard* *Dr. H. Draper has sent me an enlarged photograph of the nebula of Orion which he has recently taken. It was taken on the 30th September (1880) with an exposure of 51 minutes...The photograph shows that the larger stars were very much over-exposed, and consequently the stars are all represented by white blotches. In another and much*

shorter exposure of 6 minutes, the stars of the trapezium are seen separate. This is not the first photograph in which these stars are shown but it is the first photograph in which any nebula has made its appearance...Comparing it with these two drawings by Bond and Secchi, it corresponds with neither of them. Certain it is that the drawings differ very materially and they do not differ continuously, so that there seems to be no proof from the drawings that the nebula is slowly changing; they are not nearly accurate enough to determine anything.

Mr. Common *With regard to Mr. Ranyard's remark that we must look to photography to explain any changes in the form of the nebulae, I do not agree with him...I would rely more upon accurate drawings than upon any photographs.*

Mr. De la Rue *...I presume those large patches of light in the photograph are stars.*

Mr. Ranyard *They are over-exposed stars.*

Mr. Mitchel *...it seems to me that we have had the question raised this evening as to whether the observations made by photography are more valuable than drawings with the eye. The case is this, that if you get a definite chemical compound with which you make your plate, and you get a definite exposure and know the conditions of temperature under which the photograph is taken, that is a far more dependable result than that which may be made under the varying conditions of the brain, which varies from time to time.*

Another photograph of M42, again taken by Draper with his 11 inch telescope, recorded star images fainter than 14th magnitude. Draper speculated that increasing the exposure time still further would enable stars to be photographed which were too faint to be seen with the naked eye through the telescope. In addition to direct photography Draper experimented with spectrography and succeeded in obtaining the first spectrogram of M42 which showed two lines in the ultra-violet and traces of two others. It is a great pity that Draper's work in astronomical photography was cut short by his untimely death later in 1882. However his work had inspired others notably Janssen at Meudon and Common in England.

In a paper published in the Monthly Notices of the Royal Astronomical Society in 1883, Ainslie Common described a photograph he had taken with a 36 inch reflector again of M42 with an exposure of 37 minutes:

This photograph shows a marked advance on those I had previously shown at meetings of this Society; and

> *although some of the finer details are lost in the enlargement, sufficient remains to show that we are approaching a time when photography will give us the means of recording in its own inimitable way the shape of a nebula and the relative brightness of the different parts, in a better manner than the most careful hand-drawings.*

Common also believed that photography would enable observations to be made of stars too faint to be seen by eye. For his pioneering work in astro-photography Common was awarded the Gold Medal of the Royal Astronomical Society in 1884.

By the end of the 1880's photography was a well established scientific technique and was being used to support or refute, sometimes mistakenly, the astronomical theories of the day. A good example of this is the interpretation of his own photographs of the Great Nebula in Andromeda (M31) made by Isaac Roberts in a paper published in 1889:

> *The photograph which accompanies these notes was taken on October 1 last (1888) and it throws a very different light to that hitherto seen by astronomers upon the constitution of the great nebula, and we shall not exaggerate if we assert that it is now for the first time seen in an intelligible form. No verbal description can add much to the information which the eye at a glance sees on the photograph and those who accept the nebula hypothesis will be tempted to appeal to the constitution of this nebula for confirmation, if not for demonstration, of the hypothesis. Here we (apparently) see a new solar system in the process of condensation from a nebula - the central sun is now seen in the midst of nebulous matter which in time will be either absorbed or further separated into rings more or less symmetrical with the nucleus, and present a general resemblance to the rings of Saturn. The two nebula h44 and h51 seen as though they were already undergoing their transformation into planets. But I must refrain from further running riot with the imagination...*

It was to be over 30 years later before the true nature of M31 became apparent and appropriately that was shown using long exposure photographs taken by Edwin Hubble with the 100 inch telescope at Mount Wilson.

Our understanding of the nature of the nebulae rests on a solid foundation of observations made over the centuries by dedicated astronomers firstly using the eye at the telescope and more recently using photography and spectroscopy. One end result of these observations is that we now feel confident we can show the correctness of Sir William Herschel's speculations of two centuries ago that there are two types of nebulae!

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THE LIQUID-MIRROR TELESCOPE - AN EARLY EXAMPLE OF KIWI INGENUITY?

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(This is an expanded version of a paper presented at the 1984 RASNZ Conference)

INTRODUCTION

A liquid rotating about a vertical axis adopts the form of a paraboloid. A reflecting liquid therefore could be used as the primary mirror of a transit telescope of focal length

$$f = \frac{g}{2\omega^2} \qquad \text{(see appendices)}$$

where g is the local acceleration due to gravity, and ω the angular velocity. This fact has been known for some years, and was used in the early part of this century to construct an instrument of 0.5 metre aperture using mercury as the reflector (Wood, 1909; Wood, 1911).

An alternative approach is to spin some form of resin until the material sets. The hardened surface is then retouched to remove irregularities, and aluminized as for a conventional telescope. This method has been used several times in recent decades. For example, a group at the California Institute of Technology have constructed a 62 inch instrument of sufficient precision for use at infra-red wavelengths. The mirror actually took 3 days to solidify (Neugebauer and Leighton, 1968). A similar approach has been pursued in the Department of Electrcal and Electronic Engineering at the University of Canterbury (Dr. P.T. Gough, personal communication, 1984).

The experiments of Wood were curtailed due to the inability of the available technology to provide a sufficiently smooth drive to the dish of mercury. Irregularities and ripples were caused by jars from the driving mechanism, grinding of the rotation bearing, imprecise levelling, and variations in the angular velocity of the dish (Wood, 1909). Wood suggested that a fusable substance used to make a permanent reflector might be preferable.

Advances in modern technology have meant that many of these mechanical problems can now be overcome, and a large zenith telescope (of aperture possibly up to 30 metres, but certainly above 10 metres) is now possible using the dynamic

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(mercury) method (Borra, 1982). A 1 metre prototype has been constructed, and found to give a resolution of 0.3 arcseconds (Borra et al., 1983).

The advantages of this method include cost and attainable aperture. It is possible to make extremely fast mirrors (f/1 and better): a model of diameter 1.65m and focal length 1.5m has been constructed but not yet optically tested (Borra et al., 1984). A large instrument would be a useful adjunct to the Space Telescope, and could attain limiting magnitudes of about 26 with a 10 metre aperture. Electro-optical tracking techniques can partially overcome the limitation of it being solely a transit instrument (Borra, 1982; Borra et al., 1984).

HISTORY OF THE TECHNIQUE

In view of the above, the liquid-mirror telescope concept may be about to undergo a revival and so it would be interesting to find out who pioneered the technique. The standard text upon the history of the telescope pays little attention to it, and only Wood's experiments are mentioned (King, 1955), who quotes Ingalls (1950). Wood himself begins his paper by saying that

> *"the idea of utilizing the principle that the free surface of a liquid, rotating with uniform velocity, assumes the form of a paraboloid, in the construction of a reflecting telescope is not new (sic.). Mercury telescopes have been suggested from time to time for the past half-century, and in the early seventies one was constructed by Mr. R.C. Carrington, on Frensham Common."* (Wood, 1909).

Therefore it is not clear to whom the honour should go.

Whilst searching early volumes of the journal 'Nature' for lithographs of nineteenth-century observatories, the author came across the following insertion:

> *"Mr. Henry Skey, of the Observatory, Dunedin, Otago, New Zealand, writes in reference to the mention which is made in Nature, vol. vii, p.25, of Prof. Capocci's idea of constructing a revolving mercurial speculum for a reflecting telescope, that he would like to know if such an instrument has actually been constructed. The same idea, Mr. Skey states, presented itself to himself, and he also constructed a telescope on this principle many years ago in England without knowing that the method was engaging the attention of others. He sends an account of a mercurial reflecting telescope exhibited by him before the New Zealand Institute, Nov. 19, 1872, which is*

> *published in the Transactions of that Institute, vol. v. p.119."* (Nature, 1874).

No replies to Skey's enquiry could be found in the columns of 'Nature' for that year. Reference to the earlier volume of 'Nature' which was mentioned reveals a review by T.W.W. (=The Reverend T.W. Webb) of a history of astronomical work at the Royal Academy of Belgium (Webb, 1872). The following is the relevant passage:

> *"Then we have Capocci's idea, in 1850, of a parabolic mirror formed by the rotation of a vessel of mercury, and utilised for a telescope by a large "flat", with Krecke's suggestion that a mass of melted metal might thus be cooled into a permanent paraboloid;"*

- by using a tiltable flat the steering limitation of a mercury telescope might be alleviated. Therefore there is no direct evidence here that Capocci or Krecke (respectively Italian and Dutch; see the biographical notes at the end of this paper) actually built such an instrument; however, until an antecedant is found, they hold the laurel for its invention.

THE WORK OF HENRY SKEY

Henry Skey emigrated to Otago from England in 1860 (Scholefield, 1940). Taking him by his statement in 'Nature', he therefore constructed his first mercury telescope in the 1850s, working independently. He repeated the feat in New Zealand by 1872 at the latest. Skey can therefore be put forward as a possible candidate as first constructor of a liquid-mirror reflector, and was most certainly an experimental philosopher of some note.

Skey exhibited his model to the Otago Institute in November 1872, and his paper as read was published (Skey, 1872) in the Transactions of the New Zealand Institute (now the Proceedings of the Royal Society of New Zealand). Unfortunately, he did not explicitly state the dimensions of his telescope, but a diagram is given which shows that a plane reflector with the necessary drive was incorporated. Skey anticipated many of the advantages of this type of device, such as its optical speed. In view of the comments of Borra (1982) upon the economics of a mercury telescope, and the fact that at the time the largest instrument yet built was Lord Rosse's (uncovered, partially steerable) 6-foot reflector, Skey was remarkably far-sighted:

> *"let us suppose a telescope twenty feet in diameter: ordinarily this would require tubing at least 120 feet in length, and provision would be required for its sweeping through 300 feet of motion; whereas with the horizontal speculum, a*

> *circular building thirty feet in diameter and about sixty feet high would furnish ample space, and also allow the observer, without changing his position, to work entirely under shelter."* (Skey, 1872).

CONCLUSION

Henry Skey quite clearly had an enquiring turn of mind. In concluding his case for the liquid-mirror telescope, Skey had the following to say:

> *"...that we may be enabled to travel further into what is as yet the dark profound, and to gaze with bodily eye on what now form the manifold mysteries of the universe, must be the ardent wish of every lover of science."* (Skey, 1872).

He clearly deserves to be remembered as one of New Zealand's astronomical pioneers.

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BIOGRAPHICAL NOTES

Robert Williams Wood (1868-1955) was Professor of Experimental Physics at Johns Hopkins University, Baltimore, Maryland, and one of the foremost opticists and astronomers of the first half of this century.

Richard Christopher Carrington (1826-1875) was a Fellow of the Royal Society of London and the Royal Astronomical Society. Frensham is near Redhill in Surrey, England, where Carrington had a large private observatory (*Mon. Not. Roy. Ast. Soc., 36,* 137-142 (1876); and the U.K. Dictionary of National Biography). I can find no publication on Carrington's mercury telescope.

Ernesto Capocci (1798-1864) was Professor of Astronomy in Naples, Italy. (*Dizionario Biografico degli Italiani (Rome 1975), 18,* 588-592). Neither can I find any paper on Capocci's idea of the mercury telescope.

Friedrich Wilhelm Christian Krecke (1812-1882) was an astronomer who worked in Rotterdam and Utrecht (see J.C. Poggendorff's *"Biographisch-Literarisches Handwörterbuch", I,* 1315 (1863); *III,* 749 (1898)). The Royal Society of London Catalogue of Scientific Papers gives the following reference which could contain Krecke's concept of the molten metal mirror: F.W.C. Krecke, "Confection de grands miroirs paraboliques", *Bulletin of the Brussels Academy of Science, 18,* 363-365 (1851).

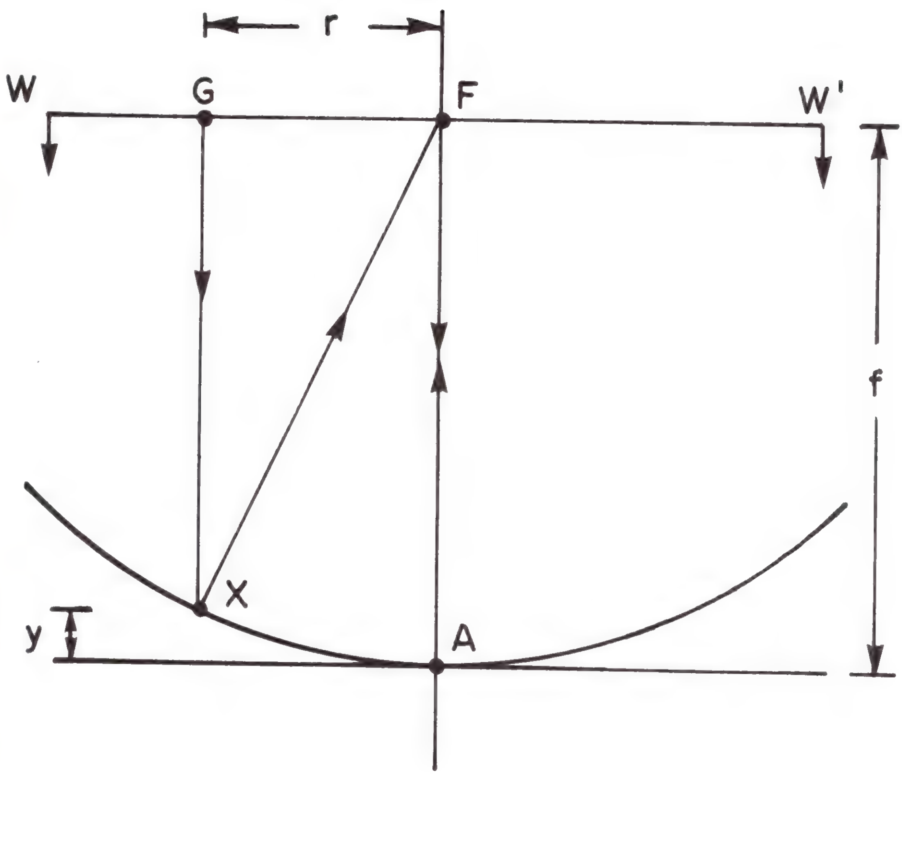
APPENDIX A

<u>To show that a parabolic mirror is required to bring a plane wave to focus</u>

The wavefront produced by a point object at infinite distance is plane. In Figure 1 consider the wavefront WW' as it passes the focal point F moving downwards. We require the condition upon the shape of the curved reflecting surface such that all parts of the wavefront are brought to a focus at F.

This condition can be investigated by stipulating that

FIGURE I



all parts of the wavefront WW' reach F at the same instant in time. Since the refractive index of the medium in front of the mirror is the same at all points, this requires that all path lengths from the wavefront to F are equal.

Consider a point on the axis A and also an arbitrary off-axis point X. The coordinates of A are (0,0) since we choose this to be the origin of measurement: the coordinates of X are (r,y). The length AF is f, the focal length.

To reach the focus, light on the wavefront at point F traverses path FAF, and light at point G takes path GXF. These two path lengths are equal and hence, applying Pythagoras' Theorem to right-angled triangle FGX, we get

$$2f = (f-y) + (r^2 + (f-y)^2)^{1/2}$$

so that

$$(f+y) = (r^2 + (f-y)^2)^{1/2}$$

and

$$f^2 + 2fy + y^2 = r^2 + f^2 - 2fy + y^2$$

from which

$$r^2 = 4fy$$

which is the equation of a parabola of focal length f.

APPENDIX B

To show that a rotating liquid adopts the shape of a paraboloid

In Figure 2 the curve represents a liquid rotating about a vertical axis. Consider a particle of mass m at point O, a radial distance r from the vertical axis, and a distance y above the lowest point of the curve.

Due to its circular motion the particle has an acceleration in the horizontal plane of

$$a = \omega^2 r$$

where is the angular velocity (units radians per second; this is 2π times the rotation rate in revolutions per second). Therefore the outward force, directed away from the axis is

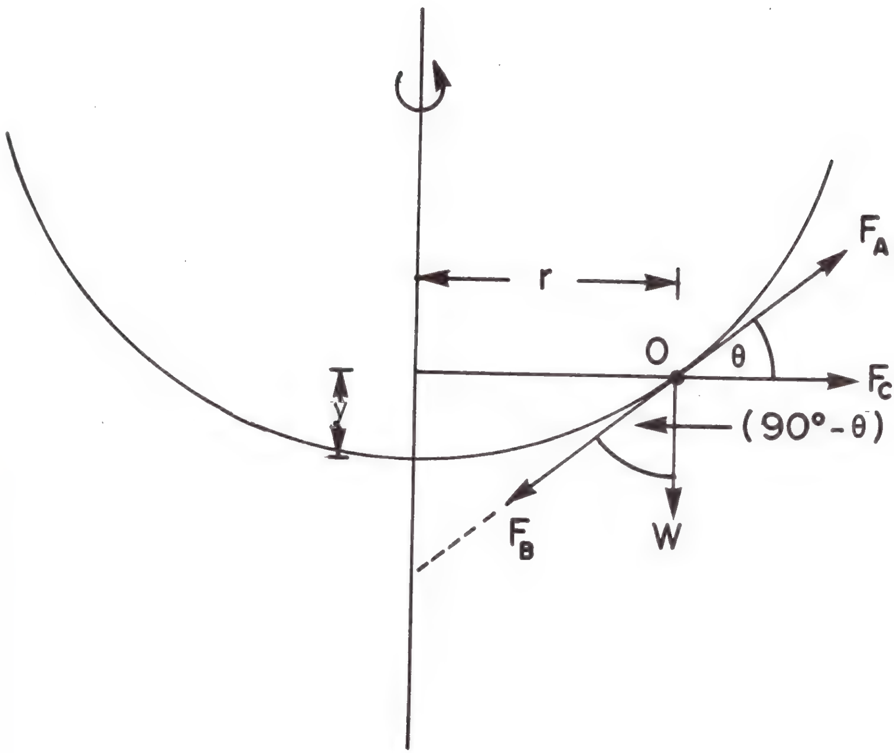
$$F_C = m\omega^2 r$$

The tangent to the liquid surface at a point O makes an angle θ to the horizontal. Thus the component of the outward force along the tangential direction is

$$F_A = F_C \cos\theta = m\omega^2 r \cos\theta$$

In equilibrium (constant angular velocity) force F_A is exactly counteracted by F_B, which is the component of the weight W of the particle resolved along the tangent. Since

FIGURE 2



the weight is

$$W = mg$$

where g is the acceleration due to gravity, F_B is given by

$$F_B = W\cos(90°-\theta) = mg\sin\theta$$

Equating F_A and F_B gives

$$\tan\theta = \omega^2 r/g$$

The slope of the curve at any point is the same as the slope of the tangent. This is

$$\frac{dy}{dr} = \tan\theta = \frac{\omega^2 r}{g}$$

This equation can be integrated to find y at any point:

$$y = \left[\frac{\omega^2 r^2}{2g} + \text{constant}\right]_o^r$$

The constant of integration is zero if the origin of the y-axis is taken to be the base of the parabola (where r=0). Thus

$$y = \frac{\omega^2 r^2}{2g}$$

Therefore at any arbitrary point (r,y):

$$r^2 = 2gy/\omega^2$$

The general equation for a parabola is (Appendix A):

$$r^2 = 4fy$$

where f is the focal length. Thus

$$4f = 2g/\omega^2$$

or

$$f = g/2\omega^2$$

is the focal length of the paraboloid formed by the rotating liquid.

* * * * * * * * *

THE HAMILTON RADIO TELESCOPE

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ABSTRACT

A radio telescope with a three metre diameter parabolic antenna has been built at the Physics Department of the University of Waikato. It operates in the 1 400-1 427MHz radio astronomy frequency band, and can detect densities of radio flux as low as 100Jy. The instrument was tested by observing transits of the Sun and the Galactic plane.

INTRODUCTION

At present, almost all information relating to distant astronomical objects must be gained by studying their electromagnetic spectrum. Originally, this was restricted to optical wavelengths. However, in recent years other regions of the spectrum have been investigated. The study of different regions of the spectrum broadens our understanding of the phenomena occurring in astronomical objects, by providing additional data.

The radio portion of the electromagnetic spectrum has gained in importance since it was first investigated about 50 years ago. The study of the non-thermal radio frequency radiation emitted by astronomical sources can yield information such as magnetic field strengths, which is unobtainable at other wavelengths.

In general, radio telescopes are operated by large scientific institutions. The reason for this is two-fold. First, the instrumentation problem posed by radio astronomy, particularly at the higher frequencies, is difficult to solve. Secondly, the large receiving antennae necessary are very costly to build and maintain. However, advances in electronics and space telecommunications have changed this situation to some extent. By using recently developed semiconductor devices, it is possible to construct the

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receiving section of the radio telescope at a much lower cost, particularly at the higher frequencies. The complexity has also been reduced by the availability of integrated circuits.

The decision to build a radio telescope at Waikato University grew out of a close association between the Physics Department and the Hamilton Astronomical Society, and the project gained impetus when the Post Office donated two microwave antennae which had formed part of the main telephone link to the south. One of these was suitably modified for use in the telescope.

Although these antennae were not ideal, either in diameter or focal ratio for radio astronomy, it was considered that they would be adequate to at least test the electronics of a radio telescope. Large modern radio telescopes are capable of detecting radio sources with flux densities as low as one thousandth of a Jansky ($1Jy = 10^{-26}$ Watts $Hz^{-1}M^{-2}$). The Hamilton radio telescope on the other hand can only receive radio sources with flux densities down to about 100 Jy, when a three metre antenna is used. However, if the radiometer (the receiving part of the radio telescope) constructed was capable of giving research standard data, the system could be upgraded later by the addition of a larger antenna.

A complete description of the design, construction, and testing of the radio telescope to the end of 1982 is contained in Gledhill (1982). The purpose of this paper is to give a general introduction to the project, and document its progress until the end of 1982.

To put the project in perspective, section two contains a brief review of Radio Astronomy in New Zealand. This is followed by a description of the design in section three. The results of the first tests of the telescope are contained in section four. Section five discusses the future of the project, and gives the authors' conclusions regarding progress to date.

RADIO ASTRONOMY IN NEW ZEALAND

There have been several previous attempts to make radio-astronomical observations in New Zealand. These have been mainly amateur, and have resulted in few published observations. The earliest attempts seem to have been those of R.F. Joyce of Kaiapoi (F.P. Andrews, Personal Communication), who in about 1947 succeeded in detecting solar radio noise at a frequency of 200 MHz with a simple dipole and corner reflector. A more elaborate installation built by T.F. Machrell at Coromandel was used to survey the galactic radio noise between the declinations of -10° and -50° at a frequency 144 MHz (Machrell, 1963). Machrell also built and operated radio telescopes at Christchurch and New Plymouth (Machrell, 1967).

Two universities have made some contribution to the subject. In 1965 the Auckland University School of Engineering began a programme in radio astronomy with the intention of providing students in the Department of Electrical Engineering with a unified research theme. A list of the theses produced is appended to this paper. The equipment underwent a number of transformations, beginning as a total-power radiometer, and later becoming a phase switching interferometer, operating at 42 MHz. After the Engineering School moved from suburban Ardmore, to the Central City, a change to a physically smaller antenna, and the higher operating frequency of 200 MHz was necessary. The level of interference was high, and only solar radiation could be reliably observed, and no further results were published after 1975. Not surprisingly, the electronics interest of these projects exceeds their contribution to astronomy.

The work at Otago University is of greater astronomical interest, being linked to a programme of research and teaching started in 1969. Two meridian transit instruments were built at Invermay (Edwards, 1972, 1975), and successful observations of flare-stars were made. In 1973 a search for dispensed emissions from the direction of the galactic centre was also made (Edwards et al., 1974). This institution has since discontinued research in radio astronomy.

THE RADIO TELESCOPE DESIGN

A radio telescope is a device for receiving and measuring cosmic radio noise. In its simplest form it consists of an antenna, which selectively collects radiation from a small region of the sky; a radio-metric receiver, referred to as a 'radiometer', which amplifies a restricted frequency band from the output of the antenna; and an indicating device which registers the radiometer output so that it may be recorded by an observer.

Radio telescopes can use many forms of antennae to collect their signals. Large parabolic dishes are most familiar, and function in much the same way as the mirrors of optical telescopes, but corner reflections and complicated arrays of dipoles are also used, especially at longer wavelengths. One such arrangement is the "Yagi" array, familiar as a domestic television antenna.

The signal is brought to a focus at a "feed point" for collection and transfer to the radiometer. At the feed point it is picked up either by a half-wave dipole or some form of horn, depending on the frequency of operation and the associated circuits used.

The radiometers may be either simple radio receivers, called "total power" instruments, or they may incorporate complex switching and stabilising circuits.

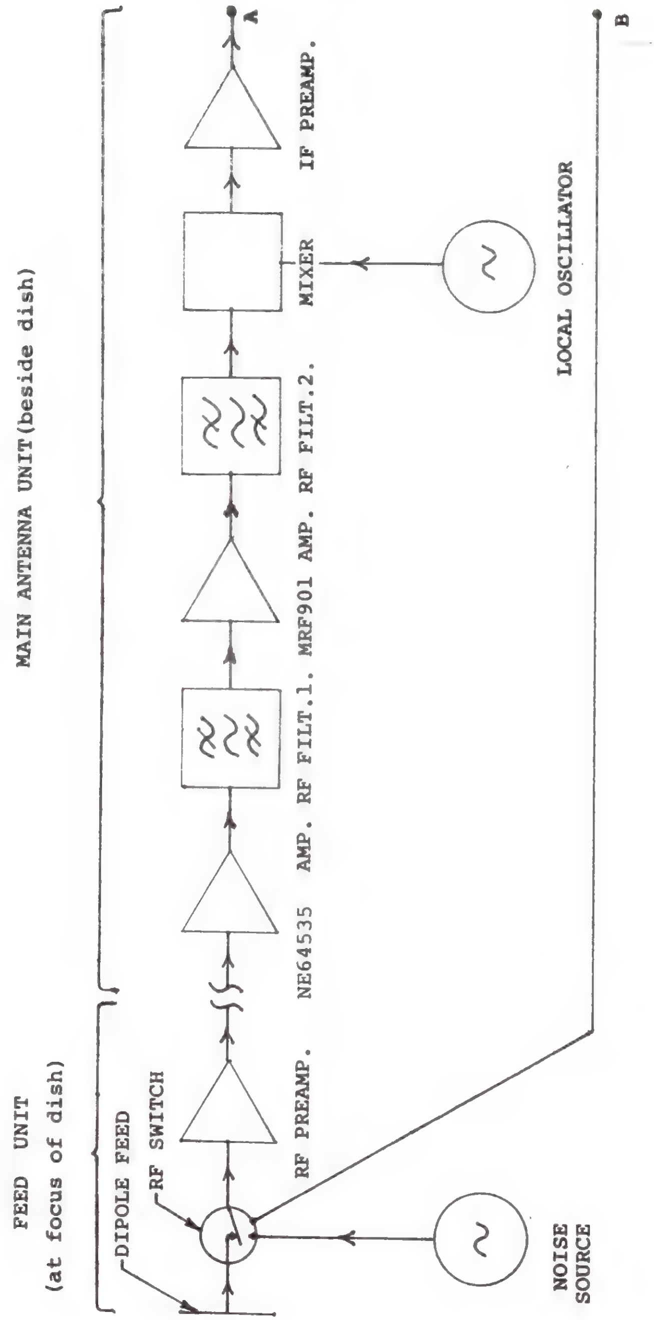

FIGURE 1a. A block diagram of the feed and main antenna units.

By using several antennae suitably spaced, and providing the necessary switching for combining or comparing the separate outputs, it is possible to increase the effective aperture, and thus the resolution of a radio telescope. Such an arrangement is called a radio interferometer.

The major emphasis of the project to date (end of 1982) has been the design and construction of a radiometer. So far, the most difficult part of the project has been reducing the unwanted noise in the radiometer. This noise arises in several ways. Some is generated within the radiometer itself, and radio interference and noise from the sky background adds more. Since the faint signals it is hoped to detect are very like the noise, it is not easy to reject one without losing the other.

The overall system design adopted is due to Dicke (1946), and is known as a Dicke switch system. The radiometer's input is switched alternately between the antenna, and a constant signal level referred to as a 'noise source'. This switching takes place many times per second. The output of the radiometer is obtained by a synchronous demodulator, which produces an output voltage proportional to the difference in power between the antenna and noise source.

Because of the very low level of the input signal from the antenna, it was also necessary to adopt a technique known as gain modulation. This technique was developed by Orhaug and Waltman (1962). It involves reducing the system gain when the radiometer is switched to the noise source, in order to match the signal and noise source levels.

A block diagram of the radiometer is shown in Figure 1. The complete radiometer can be though of as a high gain radio bridge. The synchronous generator provides a signal which modulates the system. This produces two 'paths' in time; one 'path' being the signal path, and the other the reference path. In the signal path the radiometer is looking at the antenna, and in the reference path, at a cooled, matched termination.

The radiometer is designed to operate in the 1400 MHz to 1427 MHz radio astronomy band, and has a bandwidth of 20 MHz. It has a beam width of about five degrees when used in conjunction with the three metre paraboloid.

The radiometer comprises three separate units. The first is a radio-frequency (RF) pre-amplifier mounted with the dipole at the feed point. Next comes further RF amplifiers, a mixer, and an intermediate frequency (IF) amplifier, placed beside the paraboloid, and finally, the output devices, chart recorder, and power supplies in an equipment room nearby.

The system was designed to be as modular as possible. Each individual component of the system was built as a

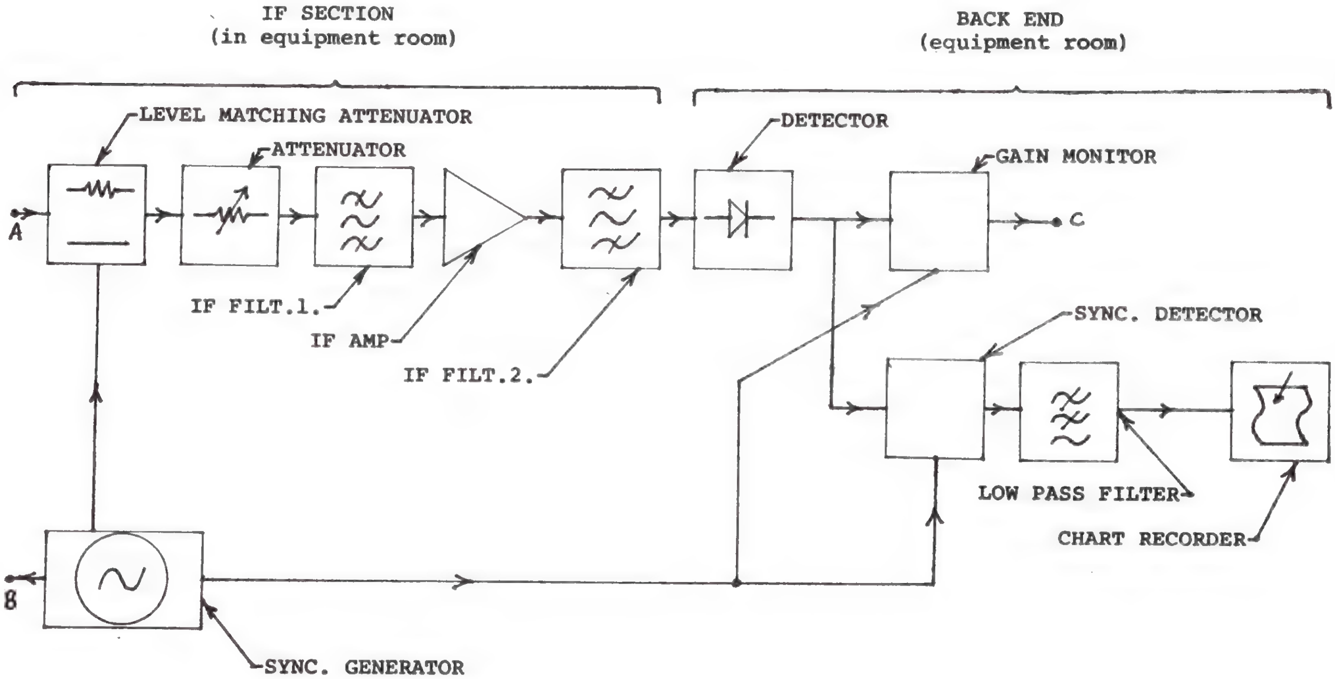

FIGURE 1b. A block diagram of the IF section and back end.

self-contained unit, and tested as such, before the system was interconnected to form the radiometer. This introduced a high degree of flexibility into the system. Any module can be removed from the system for testing, and the radiometer can be easily modified.

One of the major features of the design is the use made of Gallium Arsenide field effect transistors (GaAs FETs) in the RF preamplifier. These devices have only recently become available, and enable transistor RF amplifiers to approach the noise performance of the more exotic parametric and Maser designs (Gledhill and Liley, 1984).

TESTING AND RESULTS

When first tested in November 1981 the telescope was operated in a simplified form, with a total power radiometer, and a cheap bi-polar transistor amplifier as the first RF stage. In the final design, which became operational in March 1982, the system noise was reduced to less than a fifth of that present during the original trials.

The telescope was used during this period to observe the Sun. Figure 2 shows a typical transit of the Sun. The receiving dish was jacked into position so that the Earth's rotation produced one Solar transit per day.

These early observations were used to check the pointing accuracy of the dish, and assess the characteristics of the antenna. The worst case pointing accuracy was estimated to be better than $\pm 2°$. The antenna pattern conformed to standard theory, with a beam width of five degrees, and an effective collecting area of:

$$(2.8 \pm 0.2)\mathrm{m}^2$$

By the beginning of March 1982, the radio telescope was fully operational, although some stability problems remained. The telescope was used to observe the transit of the plane of the galaxy in the southern sky. Figure 3 shows five recordings of this 'radio source' for various days throughout March 1982, indicating the change in the time of transit caused by the Earth's movement around the Sun. Note that interference was still a major problem at this stage.

Using the recorded time of the transits, and the antenna elevation, the position of the peak intensity was found to be:

$$17\text{ hr } (10 \pm 5)\text{m R.A}$$
$$-(41 \pm 2)°\text{DEC.}$$

This corresponds to a point just one degree south of the plane of the galaxy.

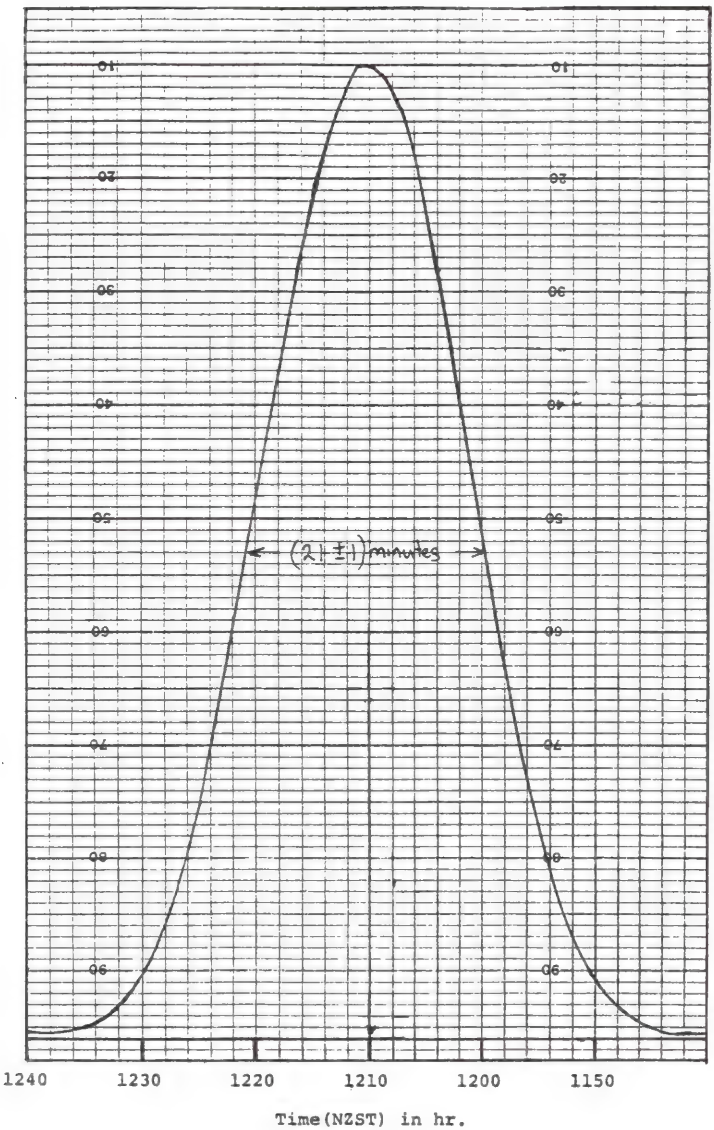

FIGURE 2. A recording of the Sun taken on 6 December, 1981.

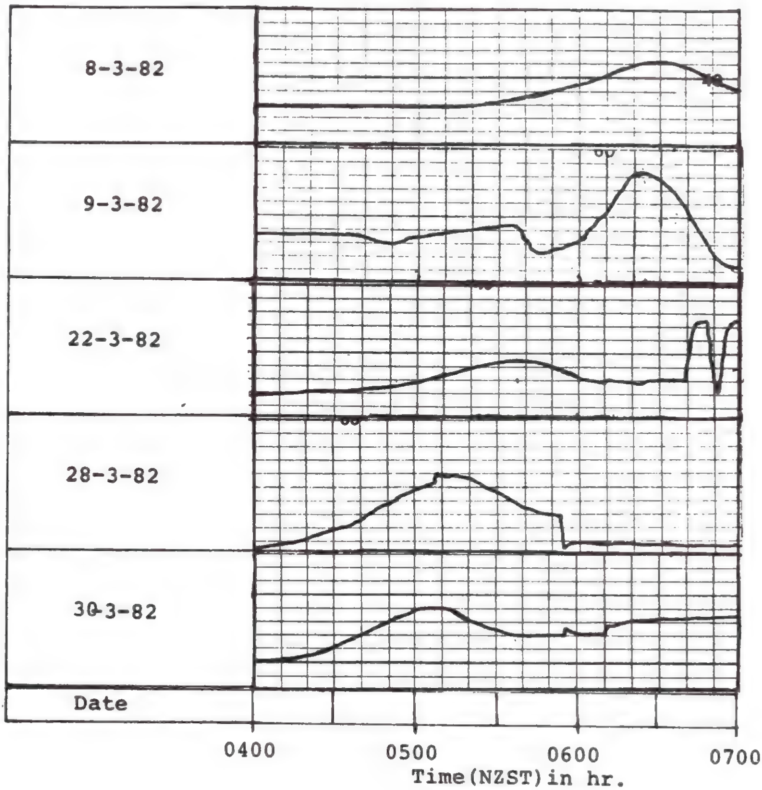

FIGURE 3. Five recordings of the transit of the plane of the galaxy made during March, 1982. The change in transit time is due to the movement of the Earth around the Sun.

Figure 4 shows recordings taken of this source, after some of the stability and interference problems had been solved. Note that Figure 4 also shows a second radio source, which, judging from its position, must be a trace through the side of Centaurus A.

The data in Figure 4 was used to estimate the sensitivity of the radio telescope. The results revealed that it had attained its design sensitivity of 100 Jy.

CONCLUSIONS

The results presented in the last section show that at the end of the first phase of the project, a research standard radiometer has been constructed. However, some problems remain. The most important of these are the lack of a good noise source, and the small size of the present receiving antenna.

There are a number of improvements required which will enhance the performance of the telescope. The most basic of these have been mentioned above. The construction of a new receiving antenna of approximately 10 metres aperture would effect an order of magnitude improvement in the sensitivity of the system. A stable noise source would solve most of the stability problems.

Other improvements suggested are the use of a cryogenically cooled GaAs FET RF preamplifier; and computer processing in the output stages of the radio telescope. A cryogenically cooled GaAs FET amplifier could be combined with the cryogenically cooled noise source, which is also required.

Gledhill (1982) suggested other improvements which would enhance the performance, and the flexibility of the system.

If most of the suggested improvements were made, the resulting radio telescope would be a useful research tool. For example, if the dish size was increased to 10 metres, and a cryogenically cooled GaAs FET first stage amplifier was used, the system sensitivity would be improved by about 60 times. The result would be a minimum detectable flux density of less than one Jy, and a resolution of under two degrees.

This stage of the project is in fact underway, with the Hamilton Astronomical Society, in conjunction with the University, and Waikato Technical Institute, commencing the construction of a 10 metre dish.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the help and advice of

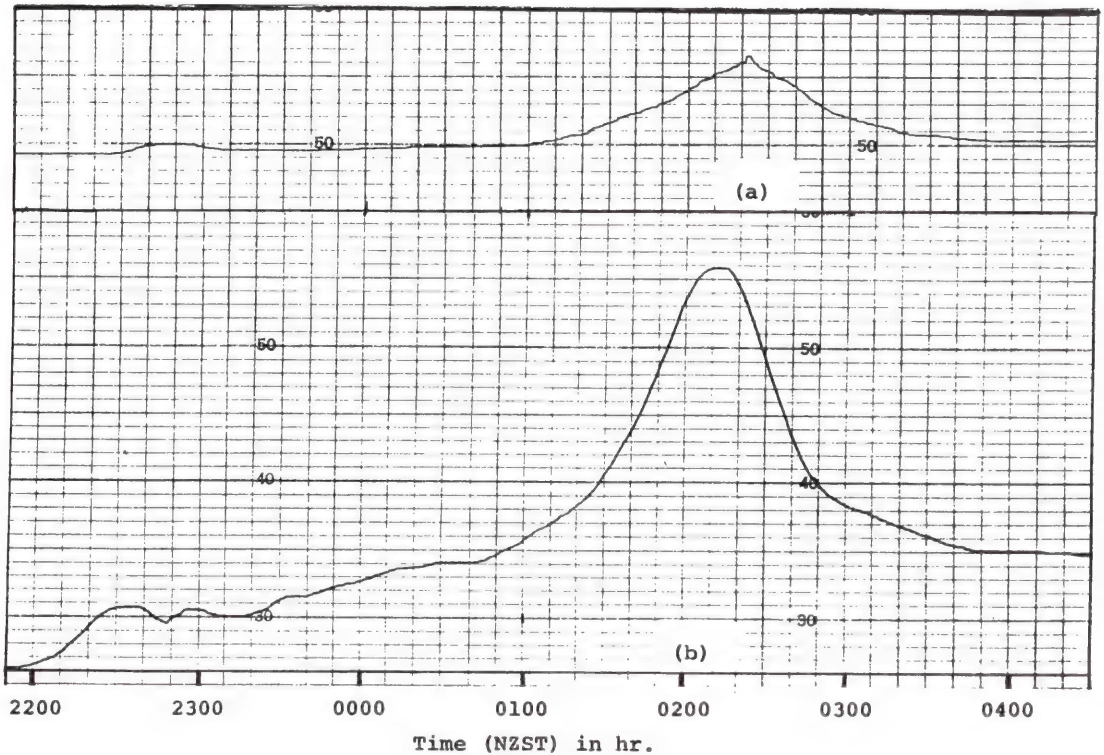

FIGURE 4. Two recordings of the transit of the plane of the galaxy.
(a) 8 May 1982, 850 Jy per division. (b) 12 May 1982, 170 Jy per division.

Mr. T. Bevan of the Post Office Radio Depot in Hamilton and Mr. R. Holdsworth of the University of Waikato Physics Department.

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SPATIAL FREQUENCY FILTERING OF IMAGES

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ABSTRACT

Spatial frequency filtering is a technique whereby the information structure of an image is changed by obtaining its two-dimensional spatial Fourier transform either digitally or optically, and attenuating selected spatial frequencies. Astronomical applications include the removal of mosaic lines from composite photographs, and the reduction of instrumental noise from stellar spectra.

INTRODUCTION

Astronomy is a field in which vast amounts of time, effort and money are spent to obtain information. It is very important to obtain as much as possible from any given observation. For this reason image processing and enhancement techniques must continue to be developed to realise the full potential of any form of data acquisition.

One technique, developed particularly during the 1950s (Holeman 1967 and references therein), is that of spatial frequency filtering. The concept of temporal frequency is familiar. In a similar fashion, spatial frequency relates how many times light and dark areas alternate over an interval of length.

The spatial frequency filtering process attenuates selected spatial frequencies, in particular those contributing to the noise or other undesirable features of an image.

THE SPATIAL FILTERING TECHNIQUE

Fourier theory shows that any periodic function can be produced by adding sinusoidal waves of certain frequencies and

Southern Stars, 31: 53-60 (1984)

SPATIAL FILTERING APPARATUS

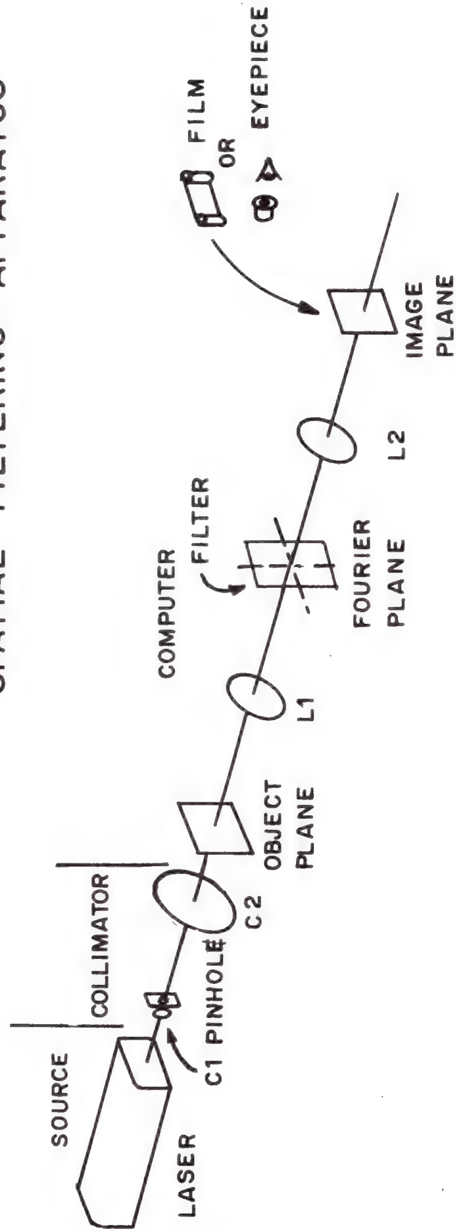

FIGURE 1

amplitudes. For example, a square wave function can be shown to be composed of sinusoidal waves of frequencies which are odd multiples of the fundamental. Non-periodic functions may be expressed in a similar fashion by using the Fourier transform. In obtaining the Fourier transform of the intensity distribution stored on a photograph, its component spatial frequencies are separated, permitted filtering.

The Fourier transform can be obtained in two ways:

(1) by converting an image into digital form (using a microdensitometer or CCD camera) and then computing its Fourier representation (eg Oppenheim and Schafer 1975); or

(2) by an optical procedure, in which a correctly processed transparency of the image is illuminated with coherent light, whereupon the intensity of its Fourier transform is observed in the focal plane of a convex lens through which the light is transmitted. That is to say, a lens is an optical computer which performs two dimensional Fourier transforms of spatial information in its object plane. Higher spatial frequencies are imaged further from the optical axis. Their distribution about the axis depends on the nature and orientation of the transparency in the object plane. For example, a series of vertical lines has as its Fourier transform a horizontal row of diffraction orders (the Fourier transform also corresponds to the Fraunhofer diffraction pattern.(Lipson and Lipson 1969) (Cathey 1974)).

Performing two Fourier transforms consecutively reproduces the original function, so a second lens reconstructs the image. The spatial frequencies composing an image are changed by placing masks in the Fourier plane, so that upon reconstruction, the information content has been altered. Careful choice of the mask enables certain information to be enhanced while undesirable data are suppressed.

Several different arrangements of apparatus will perform spatial frequency filtering, though with varying results (Warren 1976, Open University 1978). One arrangement is shown in Figure 1.

EXAMPLES OF APPLICATIONS

The arangement shown in Figure 1 was used with 50mm diameter, 185mm focal length achromatic doublets of L_1 and L_2. When a grid (Figure 2a) is placed in the object plane, a cross-like Fourier pattern is observed (Figure 2b). If a slit is placed in the filter plane to admit only one line of vertical diffraction orders, which is(the Fourier transform of a horizontal grating, then upon reconstruction by the final lens L_2, only horizontal lines will remain in the image

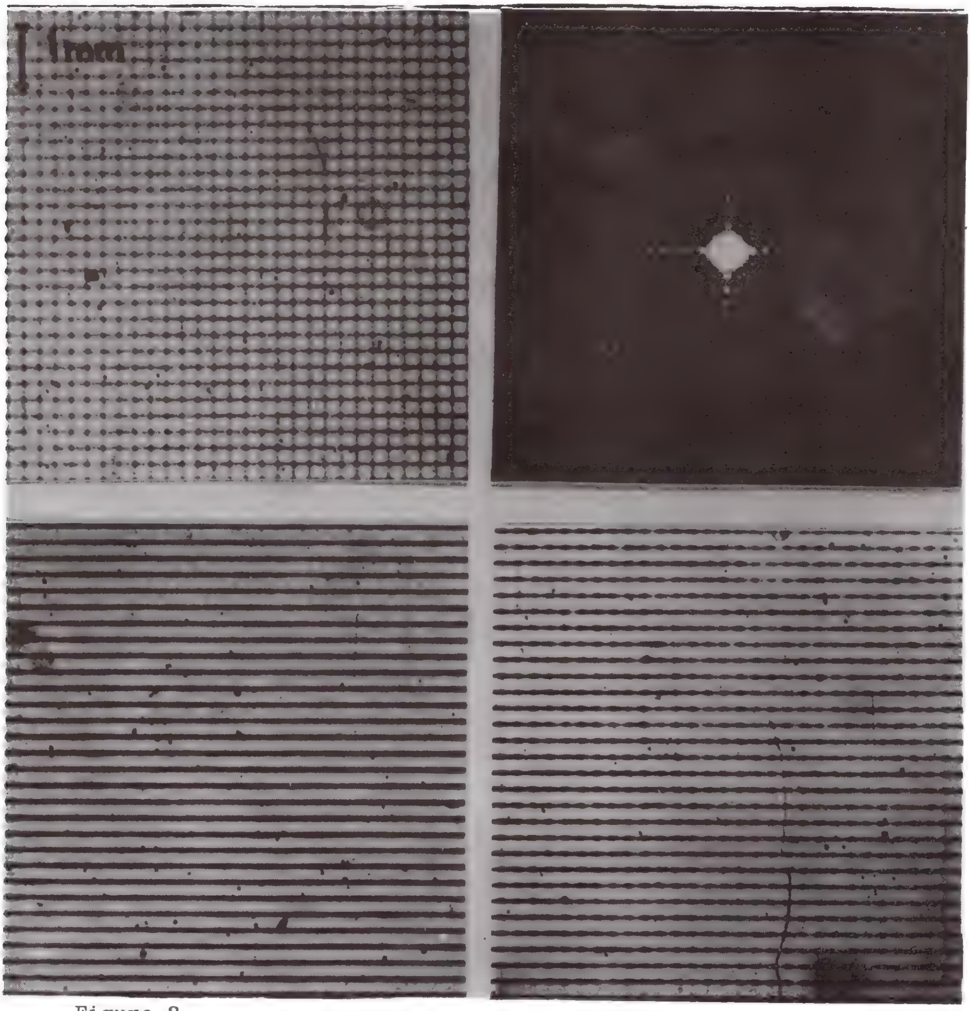

Figure 2

(a) Grid in object plane.

(b) Fourier transform of (a).

(c) Image of (a) with only vertical column of (b) passed.

(d) Like (c), but with some additional data passed.

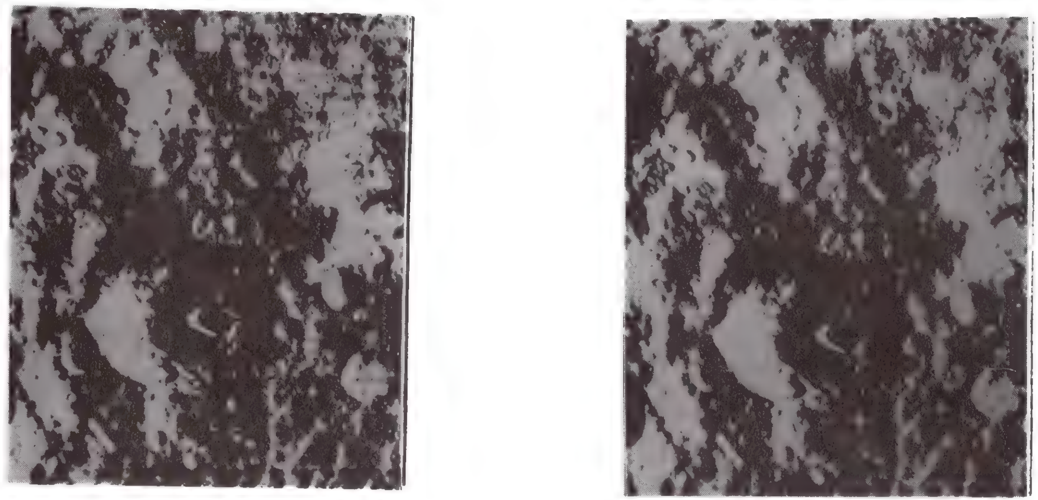

Figure 3. Unfiltered (left) and filtered photographs of Moon's surface.
(Source "Optics" by Miles V. Klein. Copyright 1970 John Wiley & Sons Inc.
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(Figure 2c). If the spatial filter slit is made just a little wider, then some of the information regarding vertical lines is barely transmitted, so they begin to just reappear (Figure 2d).

Similarly, the spatial frequencies corresponding to the regular half-tone dot structure of newspaper and magazine photographs are easily separated from those pertaining to the subject of the photograph. Masking the relevant frequencies results in an image of the same object, but without the dot structure.

An astronomical application of spatial filtering was to improve the appearance of Lunar Orbiter photographs. As the probe orbited the Moon,it scanned the surface, building up a composite picture, but which had distracting lines where successive strips overlapped. As Figure 3 shows, this feature was easily removed with spatial filtering, leaving a clearer image.

Stellar spectra show the temporal frequencies which compose the starlight. However, once the light is dispersed we obtain a spatial representation of its temporalfrequencies, either in the form of light and dark lines on a photographic plate, or as digital intensity counts along a linear array of electronic detectors. Either way, the information, once recorded, can be treated in the spatial domain.

Some spectra recorded with a linear diode array at the McDonald Observatory, Texas, were found to suffer from what they called "two-point noise", in which the counts at adjacent diodes were alternately high and low (Figure 4b). The result was a high spatial-frequency noise superimposed on the intrinsic spectrum. As the data were already in digital form, they computed the Fourier transform digitally, giving the spatial power spectrum (Figure 4a), a measure of the intensity of the transform at each spatial frequency. A peak at a frequency of 0.5 (i.e. every two diodes) indicates the two-point noise, so they filtered the data to reduce this component (Figure 4c), producing a much smoother and more representative stellar spectrum (Figure 4d).

LIMITATION

Obviously no information can be added by spatial filtering; rather, that which is present must be enhanced. While grain noise can be reduced, details comparable in size with the grain cannot be improved (Holeman 1967).

The degree of success achieved with optical filters depends upon their complexity. Filters which attenuate rather than block selected frequencies, or which alter their relative phase are capable of quite powerful operations; such as the refocussing of blurred pictures (eg Open University 1978). The production of such filters is, however, very difficult.

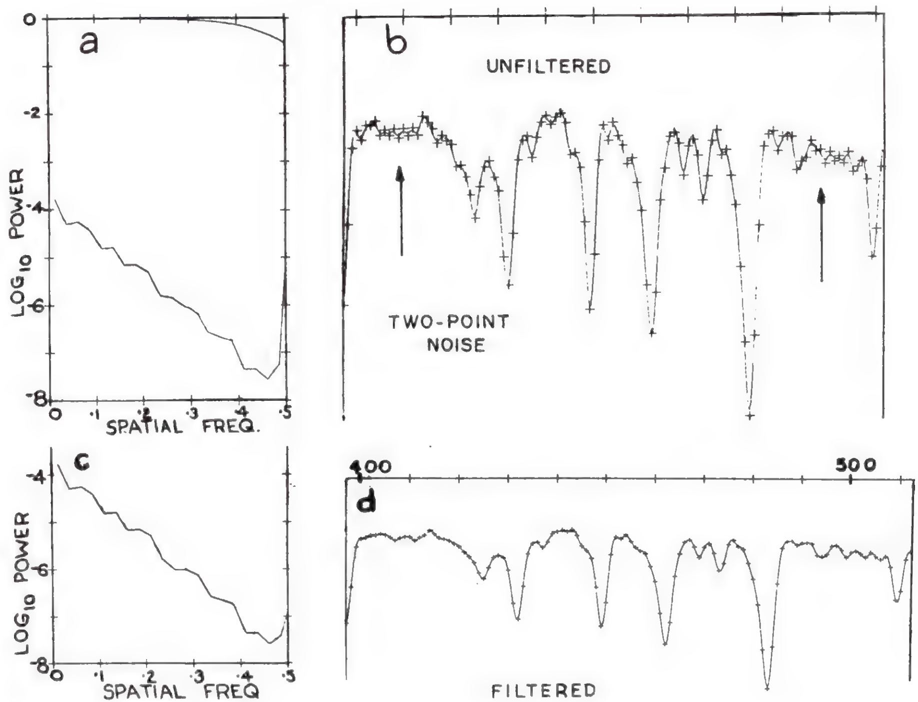

Figure 4. The unfiltered Stellar spectrum (b) clearly demonstrates two-point noise, as does its power spectrum (a). When the filter function (top of (a)) is applied, the result is the power spectrum (c) and much smoother stellar spectrum (d).

When high quality images are required, for example in the analysis of stellar spectra, digital methods have an advantage over optical systems as the latter easily succumb to noise such as that introduced from lens aberrations, seemingly inevitable dust which leads to the formation of spurious fringes, and laser speckle. DeVelis et al (1974) discuss various ways of reducing noise in optical systems.

ACKNOWLEDGEMENTS

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PHOTOELECTRIC PHOTOMETRY OF VW HYDRI DURING THE 1983 NOVEMBER SUPEROUTBURST

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ABSTRACT

Photoelectric observations made at the Auckland Observatory and at Blenheim during the 1983 November superoutburst of VW Hydri are summarised. These show a two event structure in the light and colour curves with superhumps first appearing on the third night of the outburst. Times of superhump maxima are determined and a linear ephemeris is deduced for these for the first seven days of the superoutburst proper.

INTRODUCTION

The southern dwarf nova VW Hydri was observed photoelectrically from Auckland Observatory on five nights during the early stages of the November 1983 superoutburst. In association with the Auckland observers, W.H. Allen observing from his private observatory in Blenheim, New Zealand also obtained measures on five nights.

Thirteen times of maximum of ten superhumps were obtained from the two sites allowing a linear ephemeris of

$$E_n = \text{J.D. } 2445652.8678 + 0.0769n \text{ days}$$

to be derived for these events during the first seven days of the superoutburst proper.

In this paper we present a summary of the observing coverage from the two sites (Table 1), the deduced times of maxima for the superhumps measured from both sites (Table 2), the reduced three colour UBV observations from the Auckland data (Table 3), typical light curves obtained of the event (Figures 1 to 3) and comments on the various features present in each nights' observations.

BACKGROUND

VW Hydri is a close binary system with an orbital period of 0.07427111 days, and is the brightest southern sky member of the SU Ursa Majoris subclass of dwarf nova eruptive variable stars. The system comprises a near main sequence star, filling or near to filling its Roche lobe, a small white dwarf component, and an accretion ring or disk of gas surrounding the dwarf star.

A characteristic of SU UMa stars is that they exhibit two types of nova-like outburst which brighten several magnitudes above the normal quiescent brightness. With VW Hydri the more frequent "normal" or "short" outbursts last approximately four days. The slightly brighter "superoutbursts" have a duration of approximately 15 days. Short outbursts occur every few tens of days while superoutbursts are observed at approximately half yearly intervals. Both outburst types appear quasi-periodic, but as yet cannot be predicted with a consistent degree of certainty.

During superoutbursts (only?) "superhumps" are observed which have a substantial amplitude (approximately 0.4 magnitude, reducing as the outburst progresses from maximum brightness), and a period slightly longer (3 to 5%) than the orbital period of the binary. As the outburst progresses the superhump period reduces.

At Auckland VW Hydri was first monitored photoelectrically in 1969 (Marino and Walker, 1972) during the rise to a normal short outburst. Subsequent observations have been published in Marino and Walker, 1974, and 1979, and in Walker and Marino, 1974, 1976 and 1978.

The most recent overseas review of VW Hydri is that of Vogt, 1983, which contains a comprehensive reference list of papers published during the past 15 years.

The significance of the 1983 November outburst is that an attempt was to be made to try and solve some of the fundamental mysteries of these complex systems by using the ultraviolet detectors on the Voyager spacecraft for continuous monitoring through the whole of the outburst interval. It was proposed to support these observations with data collected over a wide range of wavelengths using other available satellites and the equipment at several of the major landbased astronomical observatories. At Auckland we were primarily concerned to observe as early as possible in the outburst, as in the past this has proved to be the time when the professional facilities have been least effective in their data collecting. This objective was achieved due to prompt notification of the start of the outburst by local visual variable star observers, and a few nights of kind weather at just the right time.

TABLE 1 JOURNAL OF OBSERVING TIMES

(J.D. 2445650+)

Auckland (1)	Blenheim (2)
0.853 to 0.941	
0.972 to 1.060	
1.843 to 1.925	
	1.913 to 1.974
2.848 to 2.898	
	2.879 to 3.104
2.928 to 2.940	
2.957 to 3.045	
3.847 to 3.879	
	3.872 to 3.919
3.893 to 4.047	
	3.940 to 3.960
4.846 to 4.917	
	6.947 to 7.050
	8.968 to 9.027

Notes:

(1) Auckland photometry consisted of white light unfiltered monitoring at ten second integration time with standard UBV sets interspersed throughout each observing session.

(2) Blenheim photometry consisted of monitoring in two bands simultaneously. One band was Johnson "V" and the other white light minus "V", i.e., B + U. Ten second observations were made on both channels, with checks on the comparison star before and after each observing run. The data presented here is recorded in instrumental magnitudes.

Since this paper went to press a calibration run has determined the following transform coefficients:

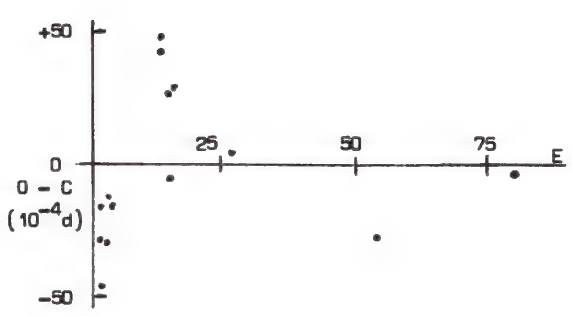
$$V = v - 0.033(B-V)$$
$$B-V = 0.837(b-v)$$
$$U-B = 1.41(u-b)$$

TABLE 2 DEDUCED TIMES OF SUPERHUMP MAXIMA

(H.J.D. 2445650+)

Superhump Number	H.J.D.	Site	Notes
1	2.8649	Auckland	
2	2.9401	Auckland	maximum after this time.
2	2.9430	Blenheim	
3	3.0186	Auckland	
3	3.0203	Blenheim	
4	3.0968	Blenheim	
14	3.8722	Blenheim	
14	3.8724	Auckland	
15	3.9443	Blenheim	
15	3.9476	Auckland	
16	4.0247	Auckland	
27	4.8686	Auckland	
54	6.9428	Blenheim	
81	9.0227	Blenheim	

Figure 4. Observed O-C deviations from the linear ephemeris of the superhump times of VW Hyi during the first seven days of the superoutburst in 1983 November.



THE OBSERVATIONS

The Auckland observations were made using the 50cm Edith Winstone Blackwell Cassegrain telescope with the Mark 1 photometer optical train and Griffiths photon detecting system as previously described (Walker and Marino, 1978). The system uses an EMI 9502 phototube with an S11 photocathode and standard three colour UBV filters. The counting interval was ten seconds and measures were recorded manually from a counter display. Each white light curve point is one ten second value. For each three colour set three ten second values were summed in each colour to give the tabulated value. The order of measurement was WWW VVV BBB UUU with the Julian Day time (Table 3) being the start of the first white (W) integration. There is a one second gap between each ten second total.

The ninth magnitude star six arc minutes southeast of VW Hyi (V = 9.40, B-V = +0.69, U-B = +0.30) was used as primary comparison star.

The Blenheim observations were made using a 32cm Dall Kirkham Cassegrain telescope with a dual channel photoelectric photometer. The photometer uses two EMI 9789 QB phototubes with a bialkali spectral response. Both tubes are supplied with the same EHT voltage. The incoming light is split by a dichroic mirror into two beams. The transmitted light passes through a V filter and the reflected is unfiltered. Each beam is monitored by a phototube. The outputs are fed into two current to frequency converters and monitored on two frequency counters. The counting interval on each counter was ten seconds. One channel was recorded manually while the other was printed out on a data logger.

The comparison star used during the observing run was the same as that used for the Auckland observations.

OBSERVED FEATURES

Night 1, J.D. 2445650.8+

VW Hydri was first measured at V = 11.60 and rising, with a typical very much reddened B-V colour of +0.4 as observed during normal short outbursts (see Figure 2 of Walker and Marino, 1978). Over the next 0.203 day the brightness increased to V = 10.27 ($\dot{V}$ = 6.50 magnitudes per day) and the B-V colour became less red to reach +0.08 ($\dot{B}$ = 8.03 magnitudes per day). The U-B was also considerably redder than normal but remained relatively constant between -0.1 and -0.2 during the observing interval, again consistent with observations of previous outbursts. In the monitoring light curves (for example in Figure 1) there is no evidence of enhancement at the orbital phase zero positions, and no indication of superhump peaks being initiated or developing at any other phase.

TABLE 3 THREE COLOUR UBV OBSERVATIONS OF VW HYDRI

J.D.2445650+	V	B-V	U-B	
0.8551	11.60	+0.38	-0.25	
0.8623	11.53	0.42	-0.15	
0.8671	11.51	0.43	-0.24	
0.9022	11.22	0.37	-0.18	
0.9127	11.17	0.26	-0.09	
0.9187	11.11	0.25	-0.21	
0.9270	11.05	0.22	-0.14	
0.9341	10.96	0.24	-0.08	
0.9741	10.67	0.20	-0.12	
0.9807	10.67	0.18	-0.06	
0.9881	10.63	0.18	-0.14	
0.9944	10.59	0.19	-0.15	
1.0036	10.52	0.19	-0.15	
1.0098	10.53	0.12	-0.16	
1.0169	10.45	0.16	-0.14	
1.0231	10.44	0.12	-0.14	
1.0300	10.38	0.13	-0.13	
1.0363	10.34	0.12	-0.15	
1.0450	10.29	0.11	-0.17	
1.0513	10.28	0.12	-0.18	
1.0586	10.27	0.08	-0.19	
1.8450	9.50	0.04	-0.65	(1)
1.8652	9.48	-0.03	-0.72	
1.8771	9.48	-0.04	-0.74	
1.9044	9.46	-0.04	-0.75	
1.9141	9.48	-0.04	-0.73	
2.8483	9.58	+0.04	-0.63	
2.8575	9.36	0.04	-0.61	
2.8632	9.32	0.02	-0.58	
2.8711	9.39	0.04	-0.56	
2.8771	9.44	0.10	-0.56	
2.8860	9.47	0.09	-0.53	
2.9303	9.29	0.01	-0.54	
2.9384	9.17	0.01	-0.52	
2.9585	9.36	0.05	-0.49	
2.9674	9.42	0.03	-0.49	
2.9737	9.41	0.06	-0.49	
2.9807	9.48	0.03	-0.54	
2.9882	9.50	0.06	-0.55	
2.9987	9.41	0.04	-0.56	
3.0051	9.28	0.02	-0.57	
3.0185	8.98	0.01	-0.53	
3.0246	9.02	0.02	-0.50	
3.0314	9.11	0.00	-0.51	
3.0377	9.20	0.01	-0.48	

J.D.2445650+	V	B-V	U-B	
3.8493	9.09	-0.07	-0.71	
3.8555	8.93	-0.07	-0.71	
3.8628	8.87	-0.09	-0.73	
3.8743	8.73	-0.07	-0.71	
3.8952	8.96	-0.03	-0.71	
3.9020	9.00	-0.09	-0.72	
3.9098	9.01	-0.06	-0.73	
3.9151	9.04	-0.08	-0.72	
3.9214	9.05	-0.08	-0.73	
3.9302	9.00	-0.10	-0.71	
3.9364	8.90	-0.09	-0.70	
3.9415	8.83	-0.12	-0.74	
3.9494	8.73	-0.08	-0.72	
3.9608	8.84	-0.09	-0.71	
3.9675	8.91	-0.08	-0.72	
3.9739	8.94	-0.08	-0.72	
3.9833	8.97	-0.07	-0.73	
3.9945	9.02	-0.08	-0.74	
4.0012	9.01	-0.08	-0.75	
4.0075	8.96	-0.08	-0.73	
4.0143	8.88	-0.10	-0.75	
4.0239	8.74	-0.07	-0.73	
4.0302	8.79	-0.06	-0.72	
4.0370	8.88	-0.08	-0.72	
4.0403	8.91	-0.07	-0.73	
4.8477	8.99	-0.14	-0.80	
4.8544	8.95	-0.12	-0.78	
4.8634	8.84	-0.13	-0.80	
4.8698	8.75	-0.08	-0.78	
4.8857	8.92	-0.10	-0.74	
4.8963	9.02	-0.11	-0.73	
4.9099	9.21	-0.09	-0.67	(2)

Notes

(1) may have twilight interference.

(2) poor data, cloud aproaching the field.

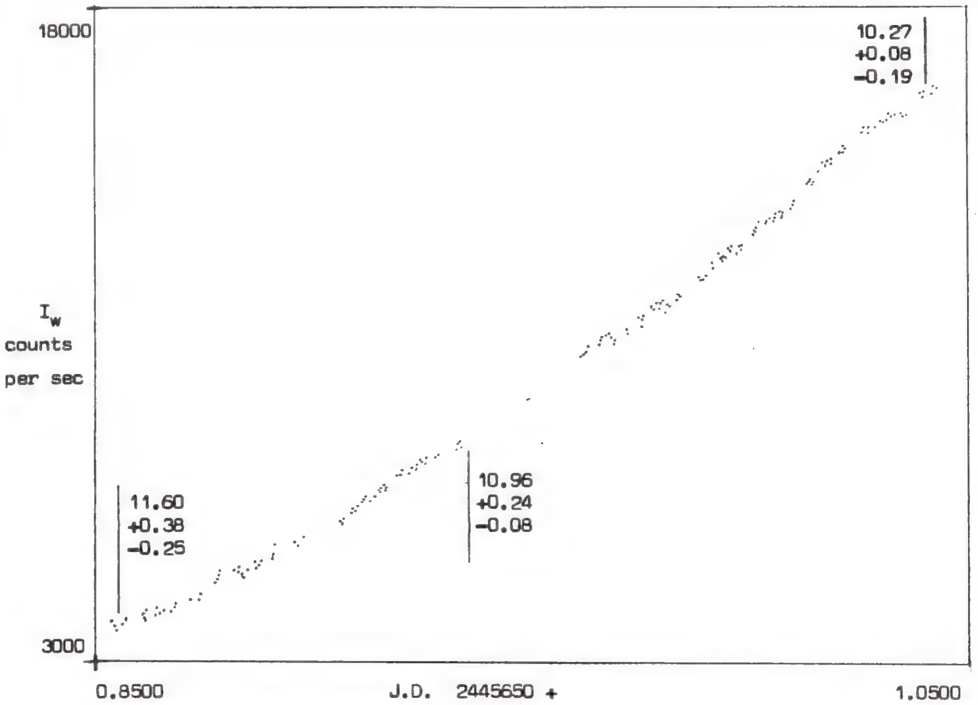


Figure 1. Unfiltered white monitoring of VW Hyi during the rise to outburst maximum on night 1.

Typical three colour values during the rise are indicated.

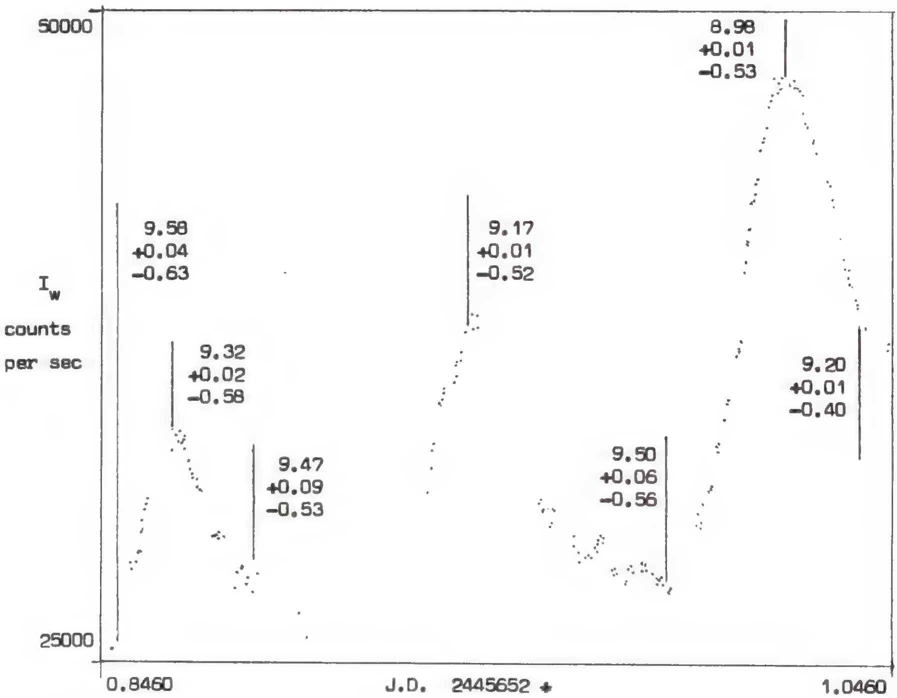


Figure 2. Unfiltered white monitoring of VW Hyi at the time of development of the superhumps on night 3.

Typical three colour values are indicated.

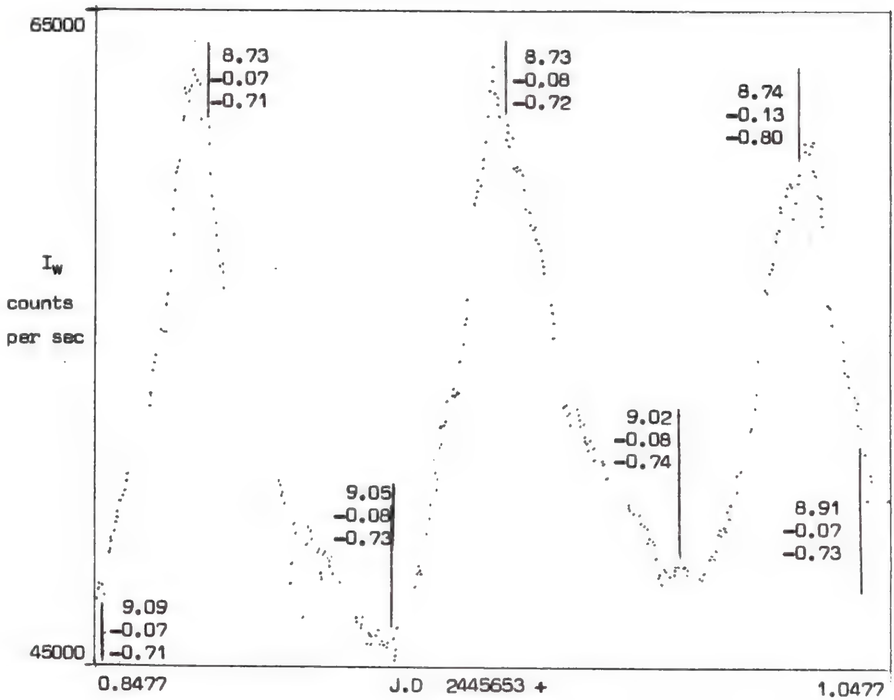


Figure 3. Unfiltered white monitoring of VW Hyi showing fully developed superhumps during outburst maximum light.

Typical three colour values are indicated.

Night 2, J.D. 2445651.8+

Over the observing interval (0.08 days) the magnitude and colours were essentially constant (V = 9.48, B-V = -0.03, U-B = -0.74) at values typical of those measured on many occasions during the maximum stage of the normal short outburst.

On nights 1 and 2 there were no observations which suggest the outburst was anything other than a normal short outburst.

Night 3, J.D. 2445652.8+

Superhumps were not observed until this third night of the outburst (see Figure 2). The first was well developed of 0.35 magnitudes amplitude about a mean brightness of 9.52, slightly fainter than the mean magnitude of the previous night. This was followed by humps of 0.42 and 0.48 V magnitude with the peaks increasing in brightness by approximately 0.16 magnitudes per cycle ($\dot{V}$ = 2.05 magnitudes per day). The time for development of the superhumps from zero to 0.35 magnitudes was thus less than 0.75 days, and probably less than 0.45 days if the increase of amplitude of the three humps observed is extrapolated back to zero.

Nights 4 and 5, J.D. 2445653.8+ and 2445654.8+

On both nights the brightness was close to the maximum level observed on VW Hydri with V peaks of superhumps at magnitude 8.73 (see Figure 3). The hump amplitude had declined to the more typical 0.3V (Vogt, 1983). The period had decreased noticably from the earlier night.

Nights 7 and 9, J.D. 2445656.8+ and 2445658.8+

Only one peak was measured on each night due to poor weather conditions at both sites. The superhumps were less well defined than previously but allowed reasonable times of maximum to be determined. No three colour magnitudes were possible on these nights.

THE TWO EVENT STRUCTURE OF THE OUTBURST

Two of the writers (Marino and Walker) have long contended that superoutbursts on dwarf nova stars always begin as a normal short outburst, and that the superoutburst proper and its associated superhumps appear at a time, which varies from outburst to outburst, after the normal outburst maximum has been reached (See for example Marino and Walker, 1979, Figures 1, 3, 4 and 9). This has recently been supported by some other observers (for example see Vogt, 1983).

The dramatic change of character of the light curve shape

on the third and following nights of this outburst, the decline which apparently occurred after night 2 before the new rise of brightness to 8.75, and the colour changes which were observed on the first night, are further evidence that on VW Hydri at least the superhumps and superoutbursts are preceded by a normal type short outburst.

SUPERHUMP EPHEMERIS

Figure 4 is the O-C diagram for the times of superhumps taken from Table 2 and calculated using the linear ephemeris deduced above. The plot show a parabolic shape of a period change decreasing as the outburst progresses. The period values from day to day are of the same order of size as those given in the early part of Figure 1 of Vogt, 1983.

ACKNOWLEDGEMENTS

Special thanks are due to O.R. (Dick) Hull, visual observer from the Auckland Astronomical Society, for once again providing early advice of the brightening of VW Hydri just before dawn on J.D. 2445650.2, and for providing regular visual brightness status reports as the outburst progressed.

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FURTHER OBSERVATIONS OF THE MIRA STAR CR MUSCAE

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Abstract

Earlier observations of the mira star CR Muscae are reviewed and the data are updated to include more recent photoelectric measurements made up to the end of 1983. A revised period of 201.6 days is determined. The erratic amplitude and shape of the V maxima and the reversed shape of the B-V colour curve continues in the more recent observations.

INTRODUCTION

CR Muscae was first observed photoelectrically at Auckland in 1972. This followed identification of the variable by R.G. Welch on photographs taken by B. Ward, P. Gordon and Welch between 1970 and 1972. Four maxima were observed between 1972 and 1974. Details of these and of the photographic observations have been published previously (Marino and Walker, 1975). From these limited data a period of 206 days was deduced with an epoch for maximum light of J.D. 2441651.

Between 1974 September and 1977 June part of three further maxima were observed. These were summarised, together with the earlier data, in light and colour curves in a paper presented at IAU Colloquium 46 (Marino et al., 1979). In particular attention was drawn to the erratic shape and amplitude of the V light curve at maximum and to the inverted nature of the B-V colour curve. One explanation for this is that like SY Fornacis and o Ceti, CR Muscae may have a fainter blue companion which dominates the B and U emission regions when the mira component is faint. Variation from cycle to cycle of impacting mass flow within the system could explain the erratic light curve.

More recently, between 1981 March and 1983 December, photoelectric measurements have been made of part of three further maxima.

In this paper we present details, in tabular form, of all observations made between 1974 September and 1983 December, a revised period using all data since 1970, and combined light and colour curves plotted to the new period.

Southern Stars, 31: 72-76 (1984)

THE OBSERVATIONS

The equipment, method of observation, standard stars and comparison and check stars used for these observations were the same as described previously. In Table 1 we list the reduced three colour magnitudes and colours for the observations since 1974 September.

DISCUSSION

While most maxima are not well covered, particularly on the rising section of the light curve which occurs very rapidly, the erratic nature of the maxima continue to be clearly evident. For example the maximum near JD 2444703 is a faint V = 10.3 and has an unusual double peak structure not previously observed on this star.

The best observed maxima is still that at JD 2441651, which is retained as the zero epoch.

To establish a revised period the times when the brightness was falling past V magnitudes 11.0, 12.0, and 13.0 have been determined. Using the light curve at the zero epoch these times have been corrected back to the maximum light position. A linear regression fit has then been applied to the resulting eight epochs (at E = -1, 0, 1, 2, 3, 8, 15, and 19) to provide a best fit period of 201.6 days.

In Figure 1 the observations for all cycles are plotted against phase using the new period. The significant feature here is again the shape of the B-V curve. The reversed shape is clearly evident and very consistent considering the large variation of V observed from cycle to cycle. The U-B curve shows a similar shape reversal.

FUTURE OBSERVATIONS

The photoelectric UBV observations provide strong support for the contention that CR Muscae is a close binary system similar perhaps to o Ceti with mass exchange occuring between the main components. A programme for further investigation involving IUE satellite observations, selected medium and narrow band photoelectric photometry, spectral observations and millimeter wavelength radio observations is currently being formulated in conjunction with overseas observers.

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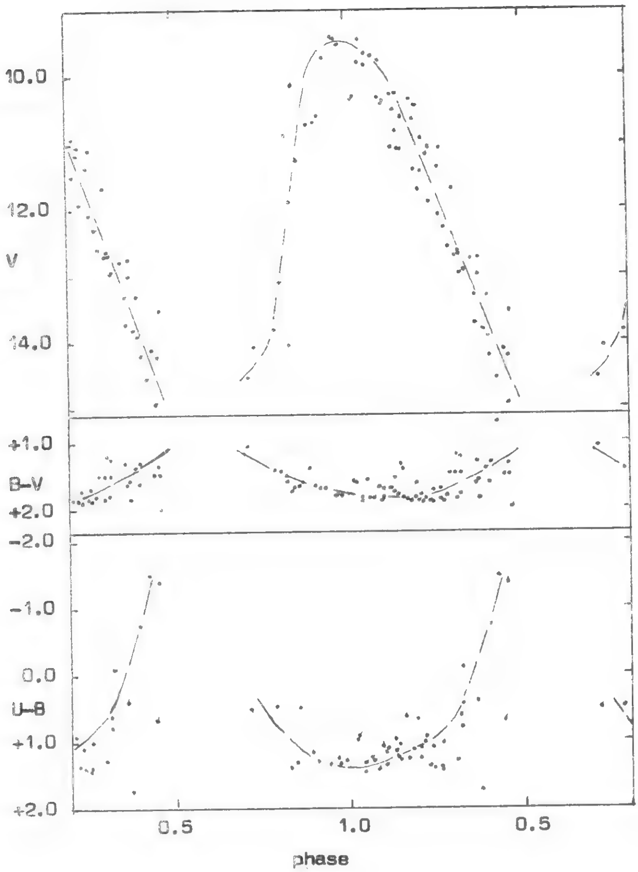

Figure 1. Three colour observations of CR Muscae covering the interval J.D. 2441511 to J.D. 2445692. Phases are computed using the ephemeris E = J.D. 2441651.0 + 201.60 days.

TABLE 1 PHOTOELECTRIC OBSERVATIONS OF CR MUSCAE FROM 1974 SEPTEMBER 11 TO 1983 DECEMBER 31 (1)

JD2440000+	V	B-V	U-B	notes
2301.86	11.06	+1.89	+1.40	(1974)
2306.87	11.36	1.86	1.44	
2325.09	12.78	-	-	(2)
2444.01	9.73	+1.69	+1.33	(1975)
2463.87	9.45	1.89	1.45	
2623.98	14.07	-	-	(3)
3226.95	10.88	+1.59	+1.41	(1977)
3230.86	10.15	1.70	1.33	
3255.03	9.43	1.83	1.26	
3256.07	9.45	1.81	1.32	
3258.85	9.51	1.82	1.29	
3269.91	9.80	1.85	1.34	
3282.98	10.40	1.82	1.13	
3291.04	10.84	1.82	1.06	
3303.88	11.73	1.78	-	(4)
4676.94	10.35	+1.59	+1.00	(1981)
4677.89	10.32	1.60	0.93	
4692.06	10.34	1.69	1.09	
4698.91	10.31	1.75	1.14	
4702.90	10.28	1.79	1.27	
4710.02	10.35	1.84	1.10	
4714.04	10.47	1.84	1.26	
4727.08	11.10	1.88	1.00	
4734.85	11.70	1.85	1.29	
4748.85	12.75	1.86	1.74	
4766.85	13.54	2.0	-	(5)
4846.01	11.27	1.66	0.49	
5505.82	11.08	+1.54	+0.98	(1983)
5510.01	11.10	1.33	-	(6)
5510.88	11.10	1.42	0.62	
5518.92	11.42	1.62	0.67	
5527.80	11.90	1.71	1.09	
5532.81	12.09	1.68	1.39	
5535.96	12.31	1.83	-	(4)
5538.03	12.59	1.49	-	(4)
5541.80	12.72	1.49	-	(4)
5544.85	12.98	1.48	-0.10	
5560.91	13.93	1.62	-0.74	
5565.87	14.55	0.7	-1.5	(7)
5571.82	14.93	1.5	-1.4	(7)
5692.93	9.84	1.57	+1.27	

Notes:

(1) Data prior to this tabulated in Marino and Walker 1975.
(2) Cloud and low counts in B and U made B-V and U-B unreliable.
(3) No significant counts in B and U.
(4) No significant counts in U.
(5) Low counts in B., no counts in U.
(6) Poor sky conditions, no counts in U.
(7) Very few counts in all colours.

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Marino, B.F., Walker, W.S.G., Beuning, J., and Blow, G., 1979, *UBV Observations of Some Long Period Variable Stars* in IAU Colloquium No. 46, Ed. F.M. Bateson, J. Smak and I. Urch, University of Waikato, Hamilton, New Zealand, 223-234.

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A STROLL IN THE REALM OF COSMOLOGY

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ABSTRACT

A review is made of the cosmological problem with emphasis on the need to resolve certain difficulties in the comparison between theory and observation before the current big-bang model of the expanding universe can be generally accepted.

INTRODUCTION

The large scale structure of the universe is usually interpreted in terms of the big-bang theory of cosmology. This choice has acquired extra support since the demise of the steady state theory and the discovery of fresh observational evidence.

The big-bang theory, that the universe evolved from an ultra high density state in the finite past, has successfully predicted the expansion of the universe, including the Hubble law of the redshift, the cosmic background radiation discovered in 1965, the He/H abundance ratio (about 28:72 by weight) and the approximate mean density of matter in space (probably within a factor of 10 of 10^{-30}g cm^{-3}).

However there are still several difficulties that prevent this interpretation from receiving complete acceptance. The main ones are:

(a) Discrepancies in the evaluation of Hubble's constant and consequent estimates of the age of the universe.

(b) Difficulties in obtaining the shape of the Hubble law curve at greater distances, and hence the deceleration parameter.

(c) The need to reconcile the value of the deceleration parameter as deduced from the Hubble curve with the observed mean density of cosmic matter as inferred from dynamical motions.

(d) The problem of the formation of galaxies.

Southern Stars, 31: 77-84 (1984)

THE EXPANDING UNIVERSE

Take an observer O (on a galaxy) and let P be another typical galaxy. In the expanding universe theory P's distance D from O will be a function of the cosmic time t. So we may write

$$D = R(t)r \quad (r = \text{constant}). \tag{1}$$

R(t) is the metric factor of expanding 3-dimensional space. The velocity of P relative to O is

$$\dot{D} = V = \dot{R}r \quad (\dot{R} = dR/dt)$$

so that

$$\dot{D} = \frac{\dot{R}}{R}D = H(t)D. \tag{2}$$

Hence velocity is proportional to distance from the (arbitrary) galaxy containing O. At the present epoch t_0 we we have the Hubble law

$$V = H(t_0)D$$

where

$$H(t_0) = \frac{\dot{R}}{R_0} = H_0 \tag{3}$$

is Hubble's constant. Again

$$\ddot{D} = \dot{V} = \ddot{R}r = \frac{\ddot{R}}{R} D, \tag{4}$$

and at the present epoch t_0 we have the (dimensionless) deceleration parameter

$$q_0 = - \frac{(\ddot{R}/R)_0}{H_0^2} \tag{5}$$

APPLICATION OF EINSTEIN'S GRAVITATIONAL EQUATIONS

In standard big-bang theory Einstein's gravitational equations are applied to a cosmic space-time geometry in which 3-dimensional space is (ideally) uniform at each cosmic epoch t, and has the postulated expanding character as modelled in Section 2. If the assumption is made, in agreement with observation, that the cosmic pressure at the present epoch is small compared with the energy density, we obtain the equations

$$q_0 = \frac{1}{2} + \frac{kc^2}{2H_0^2R_0^2} \qquad (6)$$

$$\rho_0 = \frac{3H_0^2}{8\pi G} + \frac{3kc^2}{8\pi G R_0^2} \qquad (7)$$

Here ρ_0 is the cosmic mass density (in the large) at the present epoch, k is the curvature index of 3-dimensional space, and G is Newton's gravitational constant.

There are three possibilities for the geometry of 3-dimensional space, as follows:

(i) $k = +1$; closed spherical space

(ii) $k = 0$; open euclidean space (8)

(iii) $k = -1$; open hyperbolic space.

There are then three corresponding categories for q_0 and ρ_0:

(i) $k = +1;\ q_0 > \frac{1}{2},\ \rho_0 > \frac{3H_0^2}{8\pi G}$

(ii) $k = 0;\ q_0 = \frac{1}{2},\ \rho_0 = \bar{\rho}_0 = \frac{3H_0^2}{8\pi G}$ (9)

(iii) $k = -1,\ 0 < q_0 < \frac{1}{2},\ \rho_0 < \frac{3H_0^2}{8\pi G}$

ρ_0 is called the critical density, associated with the case $k = 0$ and this model is known as the Einstein-de Sitter universe. From (6), (7) we evidently get

$$\frac{\rho_0}{\bar{\rho}_0} = 2q_0 = \Omega \qquad (10)$$

where Ω is known as the mass index.

FUTURE OF THE UNIVERSE

For the three categories (i), (ii), (iii) analysis of Einstein's equations yields the following kinematic futures:

(i) Oscillation between a big-bang state and a finite maximum 'radius', with a finite period of oscillation.

(ii) 'Parabolic' expansion over an infinite time to an asymptotic state of zero density with the matter at rest.

(iii) 'Hyperbolic' expansion over an infinite time again to an asymptotic state of infinite dispersion but with the matter particles having constant relative velocities.

COSMOLOGICAL PARAMETERS

The approximate values, or ranges, of the parameters have been found to be as follows:

(a) Hubble's constant

$$50 < H_0 < 100 \mathrm{kms}^{-1}\mathrm{Mpc}^{-1} \tag{11}$$

(b) Hubble time

$$T_0 = H_0^{-1}$$
$$10^{10} < T_0 < 2X10^{10} \text{ yr} \tag{12}$$

(c) Age of the universe

$$t_0 \leqq T_0, \text{ where } t_0 = t_0(T_0, q_0) \tag{13}$$

As the assigned value of q_0 falls to zero the corresponding value of t_0 rises towards the value T_0.

(d) Cosmic mass density

The apparent density of cosmic matter, as indicated by the dynamical motions of stars in galaxies and of galaxies in clusters, for the case when $H_0 = 75\mathrm{kms}^{-1}\mathrm{Mpc}^{-1}$, is

$$\rho_0 \sim 2.5 \times 10^{-31} \mathrm{gcm}^{-3} \tag{14}$$

In this case

$$\bar{\rho}_0 \sim 10^{-29} \mathrm{gcm}^{-3} \tag{15}$$

so

$$\Omega \sim 0.02 \text{ (or } q_0 \sim 0.01) \tag{16}$$

(e) Deceleration parameter

As deduced from the observed value of the cosmic density, using (10), one obtains

$$q_0 \sim 0.01 \tag{17}$$

However q_0 also enters into the theoretical Hubble curve which connects apparent magnitude m with redshift z (for a galaxy P as viewed by the observer O). To order z this is:

$$m_c = M_0 - 5 + 5\log_{10}\left(\frac{cz}{H_0}\right) + 1.09(1 - q_0 + \lambda^*)z \tag{18}$$

Here m_c is the observed apparent magnitude corrected for galactic obscuration and various instrumental effects, z is the redshift, M_0 is the statistically obtained absolute magnitude of the type of galaxy observed, and λ^* is a constant

proportional to the rate of evolution of the absolute magnitude of this galaxy type at the epoch of observation t_0, These observations (assuming $\lambda^* = 0$!) have given q_0 in the range

$$0.5 < q_0 < 1.5 \qquad (19)$$

with a rather large observational error. Comparing (16) and (19) we see a large discrepancy between the results obtained by the two methods.

DISCUSSION OF OBSERVATIONAL DATA

Hubble's Constant

Sandage and Tammann (1976) obtained

$$H_0 = 50.3 kms^{-1} Mpc^{-1} \qquad (20)$$

which means

$$T_0 = 2x10^{10} yr \qquad (21)$$

(The limits of error given with their results will be omitted here.)

De Vaucouleurs and Bollinger (1979) obtained, using different distance criteria,

$$H_0 = 100 kms^{-1} Mpc^{-1} \qquad (22)$$

or

$$T_0 = 10^{10} yr \qquad (23)$$

Aaronson et al. (1980) have used infra-red magnitudes (which are less affected by dust obscuration) to obtain H_0 = 95$kms^{-1}Mpc^{-1}$, in quite close agreement with de Vaucouleurs and Bollinger. Very recently van den Bergh (1984) using blue and infra-red magnitudes has reported a mean value of H_0 round 75$kms^{-1}Mpc^{-1}$, which is intermediate between the earlier extremes.

Aaronson et al and de Vaucouleurs do find that smaller values of H_0 are obtained if nearer galaxies are used, as distinct from the more distant sources which give their 'global' value of H_0, This (20% reduction) is attributed to a gravitational drag effect due to the Local Supercluster centred on the Virgo cluster. In fact a consensus of observers find a peculiar velocity of the Local Group of galaxies (reducing the apparent Hubble velocity of the Virgo cluster) of order 200kms^{-1} towards Virgo. This is qualitatively in agreement with the anisotropy of measurements of the intensity of the 3°K microwave background which indicates an even higher velocity of the Local Group

relative to this 'cosmic' standard of rest of order $400 kms^{-1}$ (Davis and Peebles (1983)). This may indicate a gravitational pull of more distant matter as well as the Local Supercluster.

Value of q_0

As noted in (16) direct observation of the amount of matter in galaxies and clusters has given the value of $\Omega \sim 0{,}02$ with the corresponding mean cosmic density (for $H_0 = 75 kms^{-1} Mpc^{-1}$) given in (14). These observations and calculations have been made by Oort (1958), van den Bergh (1961), Abell (1975).

On the other hand from the theoretical Hubble relation (18) (taking $\lambda^* = 0$) Sandage (1972), Sandage and Hardy (1973) gave $q_0 = 1 \pm 1$. A recent study by Wampler (1980) of the C IV 1549 emission line in QSO's has given a preliminary result of $q_0 \sim 1$. However these estimates neglect any possible evolution of intrinsic brightness of the source, as a secular trend with cosmic epoch. Several observers have shown recently that giant elliptic galaxies are 'bluer' than a $z = 0$ galaxy would be at the observed redshift. This has been shown also in the infra-red. Beatrice Tinsley (an expatriate New Zealander who tragically died a few years ago) used the number counts of galaxies as a function of apparent magnitude to show (1980) that typically galaxies would be about one magnitude brighter at $z = 1$ if changes found to $z \sim 0.5$ were extrapolated. Even slower evolution viz. $0.1 mag/10^9$ yr could change q_0 by unity i.e. would reduce a value of $q_0 \sim 1$ to $q_0 \sim 0$.

A low value of q_0 of the order of that found from the observed mass density would permit the correct He/H abundance ratio to be realised, as well as D/H, as generated according to big-bang theory.

Age of the universe

If $T_0 \sim 10^{10}$ yr as found by de Vaucouleurs and Bollinger and by Aaronson et al then this would be in conflict with the age of globular clusters, especially if $q_0 \sim 1$. Demarque and McClure (1977) give ages in the range $1.3 - 1.5 \times 10^{10}$ yr for the globular clusters. Sandage's value $\sim 2 \times 10^{10}$ yr for T_0 would remove this embarrassment. However these ages may not be correct. The H-R diagrams observed for stellar systems do not agree very well with theoretical models. Also there is the outstanding neutrino problem that only 1/3 of neutrinos expected from the sun are in fact observed.

THE PROBLEM OF THE FORMATION OF GALAXIES

Because of the discovery of the background 3°K radiation the problem of the formation of galaxies has become more acute, if one sticks to the conventional view that they

condensed from the expanding, gaseous medium by gravitational contraction of irregularities and inhomogeneities. The 3°K radiation is remarkably isotropic, to ~0.1%, and since the pressure of radiation dominated at earlier epochs any irregularities in the gas can have grown only since the decoupling of radiation and matter (at z ~ 1000, temperature ~ 3000°, epoch t ~ 10^7 yr). But theory indicates that the growth would be too slow by ordinary gravitational contraction to form galaxies in time.

General arguments show that formation of actual galaxies would have to start at z $\lesssim$ 10. This is essentially because the mean density of the cosmic gas at earlier epochs would exceed the present mean density in galaxies. In fact it may be significant that no quasars have been identified having z > 4, yet the optical telescopes could easily have done so. Are quasars to be associated with young galaxies, in their first burst of generation of hot blue stars, at t ~ 2 x 10^9yr? But if so how did they condense in the first place?

Many astronomers are coming to the view that galaxies formed in clusters out of superclusters like the Local Supercluster. That is, the superclusters formed first. In fact the Local Supercluster appears to be a flattened disc, its thickness being about 1/6 of its diameter, but with an outlying halo structure of clusters of galaxies and galaxies reaching out to neighbouring superclusters (Tully (1982)). On this scenario the formation of a supercluster would be the precursor of a similar process at the cluster and galaxy level. Although, as we have seen, there is a gravitational drag on galaxies in the Local Supercluster the system seems nevertheless to be still expanding.

Other superclusters have been investigated by Einasto et al (1980) and by Ford et al (1981). Einasto et al find that superclusters and cluster chains account for 80% of all galaxies and the rest are field galaxies, the former being mainly ellipticals, the latter spirals. Chincarini and Rood (1976) and more recently Kirshner et al (1981)(have shown that the superclusters are separated by voids of roughly the same dimension (about 50Mpc). According to Abell (1982) all the evidence suggests that the superclusters are flattened systems consisting of sheets and chains of galaxies in clusters extending round relatively empty regions, so that the universe has the appearance of a sponge or honeycomb.

THE SPACE TELESCOPE

The ST is due to be launched in June 1986. It will operate at an altitude of 480km, of aperture 2.4m, and is designed to detect radiation from the far ultraviolet to the far infra red with appropriate instrumentation in the focal plane. At optical wavelengths it will see down to $m_V = 28$ which is an increase of 5 mag or 100 times extra sensitivity

beyond present ground telescopes. This means the objects can be seen 10 times further. Moreover it will determine positions to a few milli-arcseconds.

The advent of the ST means that Cepheid variables, Type I supernovae, H II regions, globular clusters and other distance indicators will be detected at distances 10 times greater. Hence global values of H_0 and q_0 should be determined to much greater accuracy. Evolution of systems can be surveyed over a much longer time scale. The centres of active galaxies will be opened up for much more detailed surveillance. Whether there is a redshift cut-off in the distribution of quasars should be established and the processes by which galaxies and clusters first formed greatly illuminated. Cosmology can be expected to take a great leap forward.

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THE GEOLOGY AND GEOCHEMISTRY OF THE GALILEAN SATELLITES OF JUPITER

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(Presented at the 1984 Annual Conference of the Royal Astronomical Society of New Zealand.)

ABSTRACT

Jupiter's Galilean satellites constitute a "mini solar system" with increasing density, rock content and geological activity from the outermost, Callisto, with corresponding decrease in ice content and surficial age inward toward Io. Block models and a segmental comparative diagram are shown to compare and elucidate these interesting and diverse worlds.

INTRODUCTION

The Galilean satellites, so called because they were discovered by Galileo Galilei in 1610, orbit in a circular fashion around the solar system's largest planet, Jupiter. They constitute a "mini solar system" in their own right, with increasing density and decreasing proportion of volatiles from outermost to innermost, each moon having a near circular orbit.

The Galilean satellites are four worlds of planetary size between those of the Moon and Mercury. In pre-Voyager days, the outer two Callisto and Ganymede, were thought to be primarily water-rich worlds considerably different in composition and density from that of Io and Europa. Io was thought to have reddish-brown polar terrain with possible cratered salt flats. (Morrison et al.)

After the Voyagers flew past in 1979, the results that came back were startling. The previous pinpoints of telescopic light became planets of considerable geological and geochemical diversity, including the smoothest, the darkest, the oldest and the most active bodies in the solar system.

Each of the satellites is described in turn, from the outermost Callisto inwards toward Io.

Southern Stars, 31: 85-94 (1984)

CALLISTO

Endless rim to rim cratering is predominant on Callisto's surface with old craters having been erased by newer ones. This suggests that the surface is at least 4.1 billion years old with virtually no modification apart from more cratering, and is quite possibly the oldest surface anywhere in the solar system. (Smith, et al., 1979; Strom et al., 1981).

Callisto has a low albedo of 17%, suggesting a rock-dusted surface. Some craters, however, have penetrated the rock-dusted surface into the ice below. The density of Callisto is approximately 1.8 gm/cm^3, attesting to a half rock, half ice composition.

The ice tends to flow when impacts occur, giving rise to a lack of significant surface relief. This is most apparent from the two giant multi-ringed impact basins Valhalla and Asgard, which are similar to the Moon's Mare Orientale, but have subdued relief with up to 15 discontinuous, concentric and raised shock rims. By contrast, Mare Orientale has but three reverse faulted rocky mountainous ridges.

A possible explanation for this difference is that about 4 billion years ago, a large planetesimal impacted the surface, instantaneously melting part of the thinner ice crust, resulting in the formation of a slushy sea which shortly afterwards refroze. This refreezing preserved a series of concentric raised ridges many diameters outside the impact floor. Ice flowage occurred on refreezing, preserving and enhancing the development of a subdued relief. Later impacts excavated deeper bowl-shaped structures indicating that the crust had cooled and significantly thickened. (McKinnon et al., 1980).

On the basis of the block model shown in Figure 1 it is believed that Callisto is a tectonically dead world. A silicate core of 1 200km radius may be overlain by a frigid, weakly convective, watery mantle up to 1 000km deep (Moore et al., 1981) above which is a 300km thick frozen ice and rock-dusted crust (at temperatures of less than 140K), able to support continual early phase bombardment and huge impact structures such as Valhalla.

GANYMEDE

The largest of the Galilean satellites, Ganymede at 5 270km diameter, exceeds the diameter of Mercury. From a great distance its surface looks vaguely similar to the Moon. On closer inspection two main types of terrain occur.

1. Dark ancient polygonal terrain reserving icy rayed craters and ghost craters (palimpsests);

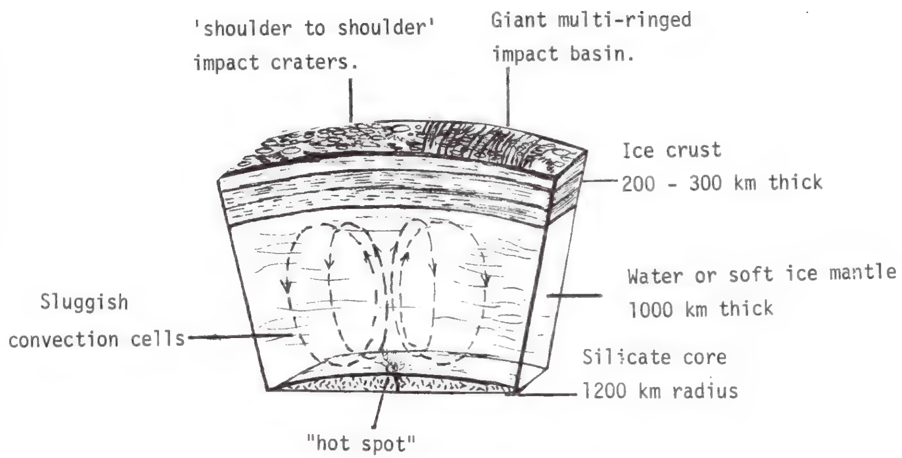

Figure 1. CALLISTO: a geological model

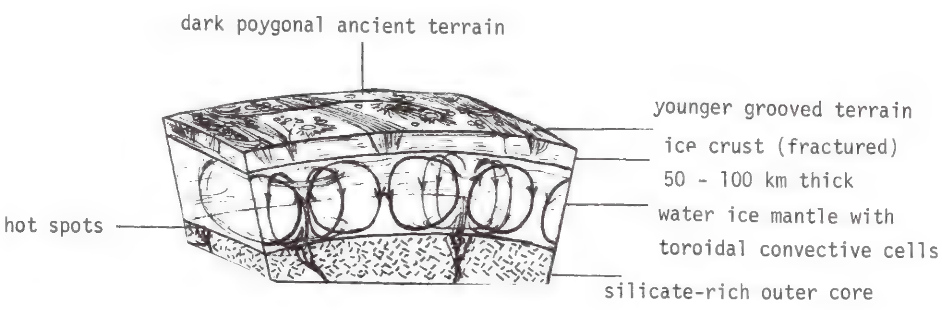

Figure 2. GANYMEDE: a geological model

2. Younger grooved terrain (sulcii) forming networks of long linear or arcuate furrows and ridges of 300-700 metres relief. (Lucchitta, 1980; Parmentier et al., 1982; Squyres, 1982; Squyres, 1983).

Ganymede,unlike Callisto, has a diverse geological landscape, but has a comparable density of about 1.9. To put Ganymede into a geological perspective, it is necessary to refer to the planet Earth and the process of plate tectonics.

The crust of the Earth consists of a number of fragmented lithospheric plates of either basaltic (oceanic) crust or silica-rich (continental) crust, riding as on a conveyor belt over the partially molten aesthenosphere, or upper mantle. The decay of radionuclides releases heat which causes rifting and addition of basalt at mid-ocean ridges (eg Mid-Atlantic Ridge). Oceanic crust is returned to the Earth's mantle at ocean trenches, where earthquakes, volcanism and mountain building occur, indicative of a compressive regime. Typical of this situation is the Taupo-East Coast region of the North Island of New Zealand. At continent-continent collision zones such as that of the Himalayas intense nappe or overturned folding occurs, forming young fold mountains, unique to Earth.

Referring back to Ganymede we see a complex geology, where packets of arcuate grooved terrain overlie one another, representing different periods of icy extrusion from the watery mantle below. With its ancient plate-like appearance, it is probably the only other world so far discovered to have undergone horizontal fault offsetting, that is, to show evidence of transform faulting. (Moore et al., 1981; Parmentier et al., 1982; Squyres, 1982). This suggests that past activity was great enough to produce tectonic blocks: icy versions of Earth's plates, being the dark ancient polygonal terranes such as Galileo Regio.

Ganymede's icy tectonic regime, however, is not consistent with that of Earth's in that only tensional tectonism occurred; with the injection some 3.8 billion years ago of packets of grooved terrain by icy volcanic eruption along areas of crustal weakness. In other words, the icy plates jostled with respect to each other, with some lateral offset and injection of ices as the crust expanded in volume and hardened. No terrestrial style compressional tectonism is believed to occur. (Lucchitta, 1980; Squyres, 1982). Such crustal expanison is a unique feature of icy bodies caused by the peculiar physical properties of water ice polymers. After differentiation of a proto-Ganymede consisting of disaggregated dust and silicate rock with high pressure ice VIII and an ice I crust, a silicate core formed with a density drop as lower pressure ices formed, causing a 6% expansion in volume. (Squyres, 1983).

The occurrence of polygonal plate-like terrain implies toroidal convective regimes of Rayleigh-Bernard character

initiated by radiogenic decay beneath a slushy ice mantle. The lesser density and smaller size of Callisto, coupled with its ancient surface unaltered by tectonic processes may argue against significant differentiation of Callisto's interior, and the presence of any significant watery mantle.

In summary Ganymede has a silicate core where the decay of radionuclides initiates hotspots which help drive toroidally shaped convection regimes in a watery mantle (Fig. 2). The ice crust fractured on formation, whereby some 3.8 billion years ago packets of ice were extruded between older terranes then modified by externally derived cratering.

EUROPA

The second Galilean satellite, Erupoa, differs markedly from the other two icy moons previously described. It has no obvious impact features or relief, being covered by a curvilinear network of light grey streaks or lineaments. The paucity of craters suggests that active resurfacing may occur. Evidence of this is from Io-derived sulphur dioxide dust which is covered by an icy frost, probably derived from an upwelling of material from the ocean below via ice-formed crustal fractures. The Europan internal structure (Fig. 3) is thought to be made up of the following features. Firstly, a hot silicate core with temperatures exceeding 2 800K is surrounded by an anhydrous volatile-rich and heterogeneous outer core where radiogenic decay occurs, forming hotspots at the base of a globally encircling water-ice ocean 40-70km deep. This in turn is overlain by a thin pack-ice crust of variable depth, consisting of frozen polygonally shaped plates with pressure ridges similar to Anarctic pack-ice. The surrounding lineament zones are locales of injection of high-pressure dirty ices from below.

Europa is thought to have a volatile-free chondritic bulk with 5% by weight of water and anhydrous comonents, with an overall density of 3.03. (Ransford et al., 1981). Dehydration of low-silica serpentinite rock may occur resulting in the release of water. The water of dehydration migrates upwards in stress-formed fractures or crustal weak points (analogous to CO_2-driven kimberlite pipe eruptions on Earth), with injection of dirty ices onto the surface by violent eruption. (Finnerty et al., 1981). An unconfirmed recent discovery has shown icy plumes up to 150km high on the Europan limb, indicating that Europa is still internally tidally active (Sky & Telescope, 1983). The crack propagates laterally along a great circle giving rise to curved lineaments.

Further freezing of the conduit promotes new stress fractures and the formation of ice pressure ridges. New cleaner ice may extrude from within, and, being less dense would tend to form lineament medial stripes. Primitive life has been postulated subsisting on hotspot vent minerals

similar to the chemotrophic ecosystems discovered at the East Pacific Rise. (Reynolds et al., 1983; Mood, 1983).

Europa is still geologically active today with three identified craters 10-20km in size, the larger ancient impacts having punched through the "pack-ice" crust with resultant refreezing of the surface. From the absence of a preserved crater record, the age of the surface must be of the order of 600 million years or less.

IO

The innermost Galilean satellite, Io, was originally thought to be rather different from the other three moons, with a lunar-like density of 3.5gm/cm³. It turned out that Io is one of the most geochemically startling bodies in the entire solar system, displaying active volcanic eruptions on a large scale. Volcanic Io has a solid core surrounded by a molten silicate mantle and a crust rich in sulphur and sulphur dioxide. (Moore et al., 1981).

Three geological models have been postulated to explain Io's unusual properties. Harold Masursky of the U.S. Geological Survey postulates sulphur-enriched silicate volcanism (Carr et al., 1979), whereas Bradford A. Smith believes that a sulphur ocean 4km deep has been forced above the silicate subcrust where flashing occurs as liquid sulphur meets SO_2. (Smith et al., 1979a). Violent sulphur dioxide decompression occurs with eruptions of sulphur and sulphur dioxide to heights of up to 280-300km and ejection velocities of 500-1 000m/s (Smith et al., 1979a; Smith et al., 1979b) with resultant extensive airfall deposits. Some of the material settles on Europa, more than 300 000km distant, as the escape velocity has been surpassed.

According to Lawrence Soderblom, in the south in the areas of fretted mesa-like terrain, gaseous-ice mixtures of SO_2 blast from fault-controlled vents at the base of cliffs (of probable solid SO_2-silicate composition) causing their erosion by basal sapping. (McCauley et al., 1979). Six to eight active plumes have been discovered erupting from Io's sulphorous multicoloured surface, resulting from tidal interaction or gravitational squeezing of Io's mantle by Jupiter and the other Galilean satellites. From this gravitational interaction, a molten mantle is formed where tidal heat generates hotspot volcanism. It is therefore the most dynamic body in the solar system with no identified impact craters. (Masursky et al., 1979; Smith et al., 1979b). This is remarkable considering that because of Jupiter being only 420 000km distant, there should be 5.3 times the cratering frequency of Callisto. (Smith et al, 1979b). This suggests that active resurfacing occurs and erasure of up to 100m of relief (including any impact craters) within one million years!

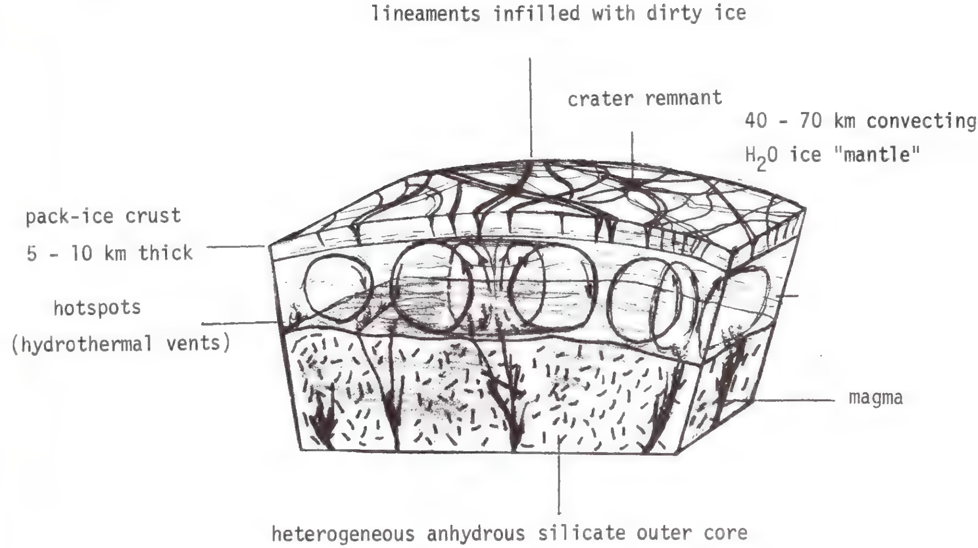

Figure 3. EUROPA: a geological model

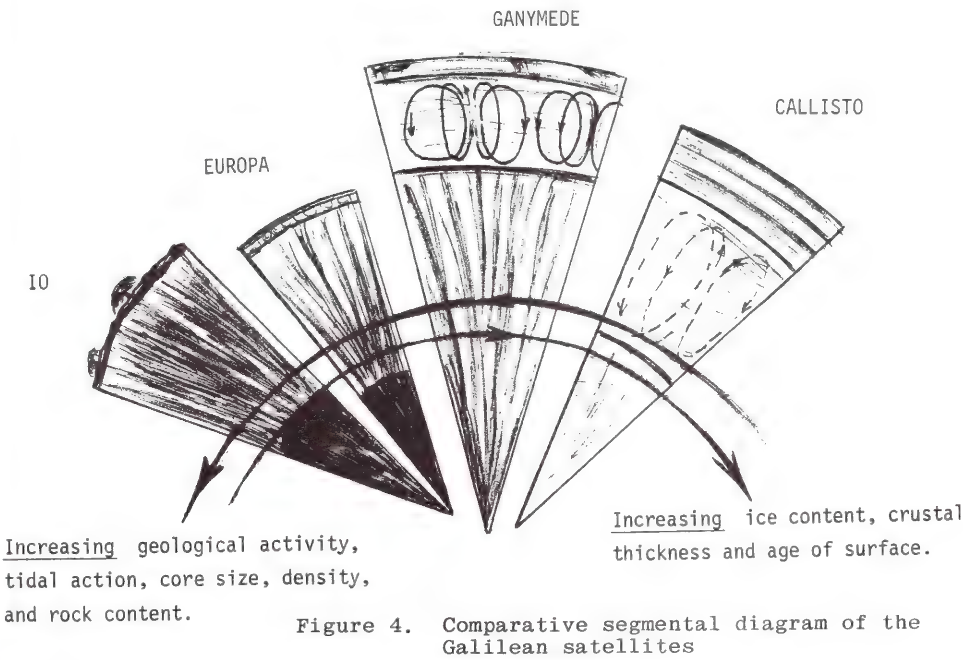

Figure 4. Comparative segmental diagram of the Galilean satellites

The eruptions are generally derived from low relief volcanic shields, usually from black sulphurous caldera lakes where the temperature exceeds 520K. Flows derived from the lakes are initially slow and viscous (being dark red in colour). With greater distance from source the flows become more sinuous and fluid, their colour changing from red to orange. At even greater distances these flows merge into yellow-orange extensive featureless plains, the colours being preserved as the surface temperature is about 135K. (Sagan, 1979). Of all the Galilean satellites, Io has the greatest range of surface expression (of $\pm$ 10km) owing to its non-ice composition, with plunging rifts and silicate mountains bouyant within the sulphur-rich upper crust. Numerous small fumarolic eruptions occur within the calderas, where small effusive domes are associated with circumcaldera faults and fractures.

One important feature of sulphur is that it has a viscosity peak at 432K, coinciding with that of the sulphur-enriched silicate mantle, giving rise to sulphur polymerisation that would inhibit convection. Hence, the 350 volcanic centres on Io (of which 6-8 active "plumes" have been observed) are relatively locked in place, perhaps like terrestrial hotspots (e.g., Hawaii).

CONCLUSION

The Galilean satellites constitute an interesting system with an increase in density, core size, rock content, and thermal evolution inwards from Callisto to Io (Figure 4), with a corresponding increase in the nearness to Jupiter and the temperature of formation from the proto-jovian nebula.

The large water-ice rich bodies Callisto and Ganymede formed in the cooler parts of the Jovian nebula where volatiles were preserved as ices. (Beatty et al., 1981). Closer to Jupiter, rocky, volatile-poor Io and Europa have similar densities to the Earth's moon. Therefore two different planetary classes are represented.

Nearer Jupiter, the effects of tides and induced gravitational interaction predominates, with active volcanism on Io, and hence a dynamic resurfacing or erosional regime. Europa's enigmatic appearance is due to the stress release fracturing of its thin icy crust, non-supportive to craters larger than 10km in size. Both Europa and Ganymede have polygonal shaped terrains, implying a convective liquid-icy mantle regime, probably still actively operative on Europa.

Ganymede shows tensional ice tectonism with grooved terrain extrusion zones within downfaulted grabens in the ancient crust.

In contrast Callisto's surface is totally unmodified by

internally driven tectonic processes over the past 4.1 billion years. Its crust has been able to support large impacts and continual bombardment but was unable to fracture as has been the case for Ganymede.

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SOME HIGHLIGHTS OF IAU COLLOQUIUM NO. 78 ON "ASTRONOMY WITH SCHMIDT TELESCOPES"

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ABSTRACT

A report is given of the proceedings of IAU Colloquium No. 78 on Astronomy with Schmidt Telescopes held at Asiago, Italy in August/September 1983

A four day colloquium on "Astronomy with Schmidt Telescopes" was held in the attractive northern Italian town of Asiago between 30 August and 2 September 1983.

Participants to the conference were officially welcomed by the Rector of the University of Padova, the Director of the Asiago Observatory and the General Secretary of the International Astronomical Union.

The subject matter of the conference could be divided into three major categories: observations and reductions, research, and future possibilities. Papers under the first two headings were evenly spread throughout the meeting whilst crystal-ball gazing was reserved for the final day.

Professor Woltjer (Munich, F.G.R.) gave the opening address on the history of Schmidt telescopes, the various surveys carried out by them, and the most effective interaction between Schmidt telescopes and larger narrower field instruments.

Dr. Cannon (Edinburgh, U.K.) described the 1.2 metre U.K. Schmidt telescope, the completed surveys and the facilities for examining plates and films at the Royal Observatory Edinburgh. He mentioned current survey work, namely the high galactic latitude Infrared survey and the celestial equatorial J-band survey plus the possibility in five to ten years of repeating the IIIa J Southern Sky Survey which would give a temporal base line of some twenty years for proper-motion work.

A paper on the automated detection of variables from Schmidt plates using the COSMOS machine was presented by Dr. Hawkins (Edinburgh, U.K.) who reported that in a typical measurement area of 16 sq. deg. for a short series of plates, to the 21st magnitude in B, the following number of variable

objects would, on average, be found: 1) Quasars and active galaxies $\sim$100 2) RR Lyr and eclipsing binaries $\sim$20 3) Cataclysmic variables $\sim$3 4) Mira variables $\sim$1 5) Supernovae $\sim$0.

A controversial contribution on the autocalibration of photographic plates by Dr. Bunclark (Cambridge, U.K.) raised more than a few eyebrows when he suggested that spot and wedge sensitometer calibrations were little better than useless.

The first day ended with Dr. Guibert (Paris, France) describing his MAMA (Machine Automatique à Mesurier pour l'Astronomie) which by 1985 will hopefully be scanning French Schmidt telescope plates at the rate of one per hour (corresponding to sampling at 360,000 10µm pixels per second). A 1024 photodiode array will be used in the machine.

Day two began with Miss Sim of the Royal Observatory Edinburgh reading a contribution by Mr. Murray of the Royal Greenwich Observatory on Astrometry with Schmidt telescopes. Of particular interest was the progress thus far made in measuring the 5800 photographic plates obtained at the Cape Observatory from 1962-70. To date 75% of the plates have been measured on GALAXY but the project is now threatened by the possibility of an untimely withdrawal of funds.

One of the rare solar system papers was given by Dr. Klinglesmith (Goddard Space Flight Centre, U.S.A.) on wide field imaging of Halley's comet in 1985/86 using Schmidt type telescopes to make temporal studies of changes in the structure of the tail.

Dr. Bidleman (Cleveland, U.S.A.) reported on the discovery of bright ($M_{pg} \lesssim 10\overset{m}{.}5$) peculiar stars in the northern sky. The results of the manual examination of 100 plates which produced 175 objects, have just been published.

Of a more general nature was Dr. Pesch's (Cleveland, U.S.A.) presentation on the Case low dispersion northern sky survey. Rather sadly he related that since he had no MAMA, COSMOS, APM or GALAXY his plates were scanned in a neolithic manner using a microscope. Objects to $B \sim 18$ catalogued from the 25 plates so far measured included 1) Blue and/or emission line galaxies 2) Probable HII regions 3) Blue and/or emission line stellar objects 4) Known and probable blue stars 5) Main sequence late B and A type stars 6) Suspected field Horizontal Branch stars of type A and F including RR Lyrae variables 7) Suspected F and G type subdwarfs showing UV excess 8) Faint carbon and late M suspected Halo giants 9) Peculiar objects (picturesquely described as the Grab Bag Category!).

Dr. Kron (Chicago,U.S.A.) spoke on the use of Schmidt telescopes in star count analysis, punctuated dramatically when he thrust the screen pointer through an Italian

chandelier! He said that Schmidt telescopes were most advantageous when looking for faint stars with a low surface density. Future work proposed included the search for population III stars, high velocity stars and the use of a IV N survey to detect stars of very low luminosity. The aim was to determine the extent and shape of the galactic halo and whether the Galaxy had two, three or many stellar components.

On the third day, a well illustrated talk was given by Dr. Carter (Mt. Stromlo, Australia) on elliptical galaxies with shells. He summarized the properties of the shells thus: 1) Shell galaxies have an elliptical morphology 2) Sharp edge features are observed at various radial distances 3) In elongated galaxies the shells tend to lie along the major axis 4) The shells are concentric but not complete 5) The shells alternate with radius (e.g. if shell 1 lies to the west of the nucleus, shell 2 lies to the east at a greater distance than 1, shell 3 lies to the west at a greater distance than 2 and so on) 6) Shell galaxies do not occur in clusters 7) They are not associated with radio sources 8) No emission lines are observed in the spectra of the shells and in general no HI is observed 9) BVRJH colours look like those of stars of types G/K 10) Some evidence that the shells are bluer than the parent galaxies. One suggestion is that the shells are composed of stars and not gas and that the stars are formed by shocks in the galactic wind where it interacts with the intergalactic medium.

A paper on the use of quasars as probes of the intergalactic medium was presented by Mrs. Pocock (Herstmonceux, U.K.). Quasars detected on UKST objective prism plates near bright relatively nearby galaxies will be used via individual spectrophotometry to examine the extent and content of possible haloes about those galaxies.

Dr. Shanks (Durhamn, U.K.) reported on the way in which galaxy number counts can be used in the study of cosmology. He used data obtained from the UKST and the AAT and measured on the COSMOS machine. Good agreement was found in the galaxy number counts obtained from six different UKST plates. However the conclusions arrived at from red and blue plate counts were contradictory. To match the blue plate counts a model in which galaxies evolve with time was needed whereas a best fit between model and observations for the red plate was obtained in the no evolution with time case!

Dr. MacGillivray (Edinburgh, U.K.) described a faint galaxy survey carried out by himself and Dr. Dodd (Wellington, N.Z.) from COSMOS measures of deep UKST plates. Measurements were made on adjacent plates and the results, in positions and magnitudes, combined to form a catalogue. Magnitudes derived for galaxies which appeared on more than one plate were found to be in good agreement with one another.

On the final day, Dr. Angel (Tucson, U.S.A.) spoke on the

future of wide-field and multi objective telescopes. Of particular interest was a novel transit instrument. This was a three mirror Paul telescope with zero Seidel aberration, a 1° field produced by a 1.8 metre primary mirror operating overall at f2.2. Objects are detected as they drift through the field of view by two RCA CCDs. The telescope is fixed pointing at +28° Declination and a strip width of 8 arcmin. covers 20 sq. deg./night to at least IIIaJ survey plate depth. The Detective Quantum Efficiency (DQE) of the system is greater than 50% (i.e. at least 50% of the incident photons are detected: contrast with a DQE of 2% for hypersensitized IIIaJ plates).

A description of the proposed fibre optic systems ($\sim$500 optical pipes) for the UKST was given by Dr. Dawe (Siding Spring, Australia). A template is prepared for the field of interest and light pipes connected to holes in the template corresponding to the position of the images under study. The pipes may then be lead off to whatever detector is needed for the investigation e.g. a spectrograph. It is hoped to have this system operating by the middle of 1984. Cloudy nights at Siding Spring enabled Dr. Dawe and Mr. Watson (Siding Spring, Australia) to consider possible designs for future Schmidt telescopes. Their final effort, appropriately acronymed LAST (Large Aperture Schmidt Telescope), was very novel with the corrector plate actually mounted in the dome and not physically connected to the main mirror housing. It was calculated that for 1 arcsec. image size the mirror and corrector plate needed to maintain alighment to better than two-thirds of a mm.

Finally moving out into space Dr. Lasker (Baltimore, U.S.A.) presented a paper on Schmidt astronomy and the Space Telescope. He contrasted the 6° field of a 120cm Schmidt with that of 1° for a 4m telescope and 3' for the Wide Field Camera on the Space Telescope. To assist the guidance system of the Space Telescope the positions of 5000 guide stars per year in the range $9.0 < V < 14.5$ will need to be known to better than 0.3 arcsec. To measure positions with this precision from both POSS and SSS plates the Space Science Institute have purchased two PDS microdensitometers and two VAX computers for the reductions.

Dr. Iye (Cambridge, U.K.) spoke on the proposed Japanese Orbiting Ultraviolet Telescope whose broad objectives are the photometry, spectroscopy and polarimetry of UV sources in selected star clusters, galaxies and clusters of galaxies. The telescope itself will be a 60cm f4 vacuum UV instrument. It is hoped that the launch date will be in the 1990s.

The final paper of the conference was given by Dr. Bruzual (Merida, Venezuela) who outlined the way in which observing programmes for future space based telescopes can be set up with the aid of predictions made via modelling techniques.

In addition to the orally presented papers there was an interesting selection of poster papers amongst which were the following:

Microspots on IIIaJ plates   Miss Sim (Edinburgh, U.K.)
Objective prism galaxy redshifts in the field around the SGP   Mr. Parker (St. Andrews, U.K.)
Images from Large Schmidt Telescopes (clear aperture 2.5m)   Mr. Brown (Newcastle, U.K.)
Hamburg Observatory Northern Milky Way Spectral Survey for Emission Objects   Dr. Kohoutek (Hamburg, F.G.R.)
The determination of the vignetting function for a Schmidt telescope   Dr. Dawe (Siding Spring, Australia)

This conference proved to be most interesting due in part to the great variety of astronomical subjects studied using Schmidt telescopes which were reported. The host Institute, the University of Padova, are to be congratulated on providing a location which was extremely attractive and conducive to after conference discussion.

My thanks are due to the Carter Observatory Board for providing part of the funds which allowed me to attend the conference and to the Royal Observatory Edinburgh (in particular Dr. H.T. MacGillivray and Miss M.E. Sim) for facilitating my travel arrangement between Scotland and Italy.

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THE ROYAL ASTRONOMICAL SOCIETY OF NEW ZEALAND (INC.)

THE 61ST REPORT OF COUNCIL BEING FOR THE CALENDAR YEAR 1983

Council is pleased to present this review of its activities for the year ended 1983 December 31.

COUNCILLORS AND OFFICERS:

President	F.P. Andrews	
Vice-Presidents	A. C. Gilmore	
	R. McIntosh	
Executive Secretary	K. I. Morse	(to June)
	G. H. Rowe	(from June)
Hon. Treasurer	B. E. Stonehouse	
Councillors	Dr. F.M. Bateson	(ex-officio)
	G. L. Blow	(elected by members)
	A.W. Dodson	(elected by members)
	J.H. Duthie	(co-opted by Council)
	C.P. Fisk	(elected by members)
	K.R. Gledhill	(co-opted by Council)
	D.R. Goodman	(elected by members)
	N.T. Munford	(apptd by Affil. Socs.)
	C.H. Rowe	(apptd by Affil. Socs.)
	N.J. Rumsey	(elected by Fellows)

Corresponding Secretary	Dr. F.M. Bateson
Hon. Auditor	E.C.D. Watson
Hon. Solicitor	W. Slatter
Librarian	J.K. Parker
Newsletter Editor	J.K. Parker
Publicity Officer	D.H. Calder
Southern Stars Editor	G.L. Blow
	R. McIntosh
Technical Secretary	N.J. Rumsey

ASTROPHOTOGRAPHY COMPETITION:

A total of 8 entries were received from 4 entrants, the standard of work produced being of a high calibre. Mr. W. Laan (Auckland) won the Artistic Section with an early morning photo of the Moon and Venus, whilst Mr. H.O. Williams' (Auckland) series of an unusual star in NGC 2346 won the Technical Section.

CARTER OBSERVATORY:

Council is grateful to the Director and staff at Carter Observatory for their continued co-operation on many occasions during the year.

Southern Stars, 31: 100-112 (1984)

CONFERENCE:

The Society held its annual conference at Victoria University, Wellington, from the 13th to 15th May 1983. The conference was hosted by the Wellington Astronomical Society, and a good turn-out was noted. Some 18 papers were delivered to 128 registrants. Featured speakers were Dr. P. Moore and Dr. W.I. Axford. Members attending declared the conference to be a most enjoyable event, and Council is grateful to the organisers for their hard work.

GIFFORD MEMORIAL LECTURESHIP SCHEME:

During the year Council received and approved applications for lectures by 4 Gifford Memorial Lecturers.

Dr. W.D. Orchiston spoke to the Auckland Astronomical Society on May 25 on 'The Realm of the Planetary Nebulae'.

Mr. F.P. Andrews presented a weekend seminar to the Ashburton Branch of the Canterbury Astronomical Society from the 26 to 27 August.

Mr. G.L. Blow spoke to the Canterbury Astronomical Society on 20 September on Occultations.

Mr. R.R.D. Austin presented a lecture on 'Saros and Solar Eclipses....an Explanation' to a combined meeting of the Wanganui and Hawera Astronomical Societies held on September 21st.

KINGDON-TOMLINSON TRUST:

Council received 3 applications for grants from this Trust. The Trustees approved the following grants:

March	Dr. W.D. Orchiston (toward travel costs to visit NZ and present a paper at conference)	$400
April	Dr. E.Budding (toward travel costs to attend and present a paper at IAU Colloquium 80)	600
December	Hamilton Astronomical Society (toward building costs of Hilldale Observatory)	1,500

A grant made to the Wellington College in 1981 was returned to the Trustees as the moneys had not been utilised.

An approach to the Trustees for a contribution to the Prince and Princess of Wales Award Scheme (administered by the RSNZ) was turned down.

KINGDON-TOMLINSON JUNIOR ESSAY COMPETITION:

The 1983 competition attracted 10 entries, all of which were of a good standard. The judges found it difficult to separate two of the entries, so for the first time in the competition it was decided to bracket them and make first equal awards. The successful essayists were David Durham (Upper Hutt): "The Use and Development of Photography in Astronomical Research", and Alan Mooney (Hawera): "Black Holes".

LIBRARY:

The installation of a filing cabinet intended for a file of historical material has prompted a reorganisation of the Library. This work is by no means complete, but work is continuing.

MEETINGS:

The Society met once during 1983, holding its Annual General Meeting at Victoria University, Wellington. The meeting was attended by 49 members and 29 visitors. Members carried with acclamation a motion that Dr. Patrick Moore be elected an Honorary Member of the Society.

The full Council met 8 times during the year, while its Executive Committee met once.

The Affiliated Societies Committee met once, discussing a number of matters including National Astronomy Week and future Society meetings.

MEMBERSHIP:

The membership changes during the year can be summarised as follows - 38 new members, 1 new Honorary member and 1 Affiliated Society were elected and 7 resignations were accepted. Membership now stands at:- 323 members, 11 Fellows, 3 Honorary members and 24 Affiliated Societies.

Council records with regret the death of Mr. F.H. Clift, a past President of the Society, as well as the deaths of two distinguished Honorary Members; Dr. C.D. Shane and Prof. B.J. Bok.

MURRAY GEDDES MEMORIAL PRIZE:

Council was pleased to award the Murray Geddes Memorial Prize for 1983 to Graham L. Blow of Wellington. Graham's contribution to astronomy has been extensive and includes observational work as well as taking an active part in Society

affairs.

Graham founded the Occultation Section of the Society and then has actively encouraged this work with enthusiasm.

Graham joined the Society in 1974 and was elected to Council in 1980. Prior to becoming involved in Society affairs Graham had already been Chairman and Editor of the National Committee for Student Astronomy and also a Councillor and Vice-President of the Auckland Astronomical Society.

Since joining Council Graham has been involved in a number of major projects, notably the National Astronomy Day/Week programme and the 1983 Patrick Moore Tour, taking a key role in each case. In addition he was on the organising committees for the 1981 and 1983 RASNZ Conferences and co-editor of Southern Stars 1982-1984.

Through this award Council recognises Graham's selfless devotion to astronomy and his enthusiasm which is an inspiration to us all.

PATRICK MOORE VISIT:

During 1983 the RASNZ organised and promoted a lecture tour of New Zealand by the well-known British astronomer, Dr. Patrick Moore. This tour took in 16 centres over a period of 5 weeks, with Dr. Moore making 18 presentations to over 3500 members of the public and local astronomical societies. Media interest was high, with a number of items on radio and television, which provided excellent exposure for the National Astronomy Week with which the tour coincided.

This tour was a major one and involved either direct financial or travel assistance from the British Council, Kingdon-Tomlinson Trust, McKenzie Education Foundation, Victoria University of Wellington, and Air New Zealand, to whom the RASNZ expresses its gratitude. Thanks are also due to the Carter Observatory for organisational assistance, and the many regional organisers in the centres which Dr. Moore visited. Special thanks go to Dr. Moore himself, who gave so willingly of his time and expertise to promote astronomy within New Zealand. However, with due respect to the valuable assistance listed above it should be known that this visit was originated (during a visit to the U.K.), promoted and brought to fruition by Graham Blow who assumed direct responsibility for the immense amount of detailed organisation inevitably involved in such a comprehensive itinerary. That the tour was an outstanding success was a direct tribute to his dedication and to an organisational ability of a very high order, deserving of the warm thanks not only of the astronomical community but many others who had the pleasure of attending Dr. Moore's lectures.

NATIONAL ASTRONOMY WEEK:

1983 saw the most ambitious promotion to date, with considerable publicity surrounding the visit of Dr. Moore. Through this visit, Astronomy Week was, for the first time, promoted on television via the "Science Express" programme.

In addition the RASNZ again made available to local Societies promotional material including a poster, reproducible star charts for April and May, introductory astronomy pamphlets and planispheres, "Getting Started in Astronomy" cards from the New Zealand Council for Recreation and Sport, two pamphlets from Carter Observatory as well as their Handbook.

In terms of overall promotion this Astronomy Week must be judged as a success. However it is still of some concern that not every Society is prepared to put its complete weight behind the scheme and this, together with other factors, has resulted in no Astronomy Week being scheduled for 1984.

PUBLICATIONS:

The Society's two publications, Southern Stars and the Newsletter have continued under the guidance of their respective editors during the year.

Four issues of Southern Stars totalling 370 pages were produced, including the 209 page Proceedings of the Second New Zealand Symposium on Photoelectric Photometry which has been well received both here and overseas. The past year has seen a slight change in production technique, with the transfer of typing services to a centre other than that in which the editors reside. This has resulted in minimal delays being experienced, despite earlier fears of a substantial increase in production time. Thanks are due to all who contributed papers during the year, to the referees and to the typists Mesdames Ives and Scott. The editors, Messrs. Blow and McIntosh, who so ably accepted editorial responsibility on a temporary basis have given notice of their resignations, to take effect following the March 1984 issue. Sincere gratitude is due to these two gentlemen for the excellent standard which they maintained.

1983 saw ten issues of the Newsletter and the innovation of a new format with the aim of facilitating production and making easier, more attractive reading. The Gestetner and much of the stockpile of paper has been sold, offsetting some of the initial rise in cost of the new printing method. Thanks are due to Judy Parker for achieving a high standard of publication.

RULES:

A Rules Revision subcommittee of four has spent considerable time overhauling the existing Rules in preparation for republication. Various anomalies have been removed and changes made to facilitate the running of the Society. The draft has been perused by Council and is currently with the Honorary Solicitor for his examination.

OTHER ACTIVITIES:

The Society lapel badge project was successfully completed with a good response for orders being received as well as favourable comment.

The request for submissions on the proposed Scientific Advisory Committee met with a poor return of only 3 replies.

The survey of property in which the Society has an interest was completed. One result of this survey was the return of an unused grant which has been made to the Wellington College.

The list of people willing to present Gifford Memorial Lectures was updated and now comprises 16 willing speakers.

The Society had a change of Honorary Solicitor during the year. After many years of service Mr. J.J. Watts indicated his desire to step down from this position. Our sincere thanks go to Mr. Watts for his valuable assistance. Mr. W. Slatter kindly offered his services to the Society.

During the year Council set up a number of subcommittees to undertake specific tasks. In this manner investigations were made of the Photographic Competition Rules, the Kingdon-Tomlinson Junior Essay Competition Rules and the role of the Affiliated Society Councillors. In addition the standing Editorial and Advertising subcommittees were amalgamated into the Publications Subcommittee.

The year proved to be a busy one for those serving on Council. It is hoped that members feel some benefit from the work done by Council and continue to support those who so willingly work towards the betterment of the Society as a whole.

F.P. Andrews
President

G. H. Rowe
Executive Secretary

TREASURER'S REPORT:

This year we have achieved a happier result with an excess of income over expenditure of $1129.85 against an excess of expenditure in the previous year of $1424. This result has been helped by the grants of $500 each from the Ministry of Recreation and Sport and the Todd Foundation. In addition contributions toward the production of 'Southern Stars' vol. 30 no. 1 amounting to $2157 were a material factor. This sort of assistance will probably not be available in 1984 and the increase in the subscription rate will have to be relied on to meet any additional expenses.

BALANCE SHEET

The National Bank of New Zealand Ltd. $3352 increase $1830
Reflecting the healthier state of our finances.

Current Liabilities:
Subscriptions in advance $1778 increase $618, thanks to prompt payment of subscriptions for 1984.

Sundry Creditors: $1642 increase $1434
Mainly for cost of Carter Observatory Handbook, BAA Handbook and lapel badges to be paid in 1984.

Kingdon-Tomlinson Bequest: $92 decrease $1000
Payments made were

Patrick Moore visit	$1000	(provided in 1982)
E. Budding	600	
D.W. Orchiston	400	
	$2000	

An amount of $200 granted to Wellington College Observatory for repair work was not used and has been returned to the Trustees.

Gifford Lecture Fund Working Account: $1111 decrease $11
Interest income of $812 covered grants made to

G.R. Nankivell	$ 174
D.W. Orchiston	190
F.P. Andrews	204
G.L. Blow	191
R.R.D. Austin	50
	$ 809

Accumulated Fund: $4829 increase $1130
A pleasing result.

INCOME AND EXPENDITURE ACCOUNT

1983 Excess income	$1130
1982 Excess Expenditure	$1424

THE ROYAL ASTRONOMICAL SOCIETY OF NEW ZEALAND (Inc.)

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDING 31st DECEMBER 1983

1982	Expenditure			1982	Income		
3303	"Southern Stars"	$4866.75		4487	Subscriptions		$4846.42
483	"Newsletter"	607.11		292	Interest		305.39
		5473.86		106	Advertising		420.50
26	B.A.A. Handbook	-		34	Donations & Miscellaneous		136.01
167	Carter Observatory Handbook	202.07		-	B.A.A. Handbooks		259.14
			5675.93	-	Grant Todd Foundation		500.00
	Other Expenses			439	Publications - Sales	705.17	
110	Subscription to Royal Society	77.45			" Contributions to		
22	Murray Geddes & Astro-				Vol. 30/1	2157.44	
	photography Competition	52.06			" Grant by Ministry		
12	Bad Debts	96.00			of Recreation & Sport	500.00	3362.61
58	Depreciation	56.90					
261	General Expenses	15.49					9830.07
100	Honoraria	25.00					
1563	Postages	1826.63					
577	Stationery	774.76					
100	Subsidy National Astronomy Week	-					
-	Travelling Expenses	100.00	3024.29				
			8700.22				
-	Excess of Income over Expenditure		1129.85	1424	(Excess of Expenditure over Income)		-
6782			$ 9830.07	6782			$ 9830.07

THE ROYAL ASTRONOMICAL SOCIETY OF NEW ZEALAND (Inc.)

BALANCE SHEET as at 31st DECEMBER 1983

1982	Liabilities		$	
1160	Subscriptions in advance		1777.79	
208	Sundry Creditors		1642.70	
				3420.49
	Specific Funds			
1092	Kingdon Tomlinson Bequest		92.08	
5000	Gifford Lecture Fund	5000.00		
1122	" Working a/c	1110.75		
			6110.75	
50	Provision for Library and Furniture and Fittings		50.00	
				6252.83
	Accumulated Fund			
	Balance 31/12/82		3698.95	
	Plus Excess of Income over Expenditure for 12 months to 31/12/84		1129.85	
3699				4828.80
12331				$14502.12

1982	Assets		$	
	Current Assets			
1522	The National Bank of NZ Ltd.		3352.17	
632	Post Office Savings Bank		715.26	
500	Post Office Investment Account		500.00	
48	Cash in Hand		149.68	
128	Subscriptions in Arrears		172.00	
394	Stationery on Hand		385.86	
				5274.97
	Investments			
300	NZ Government Stock		300.00	
900	General Finance Ltd.		900.00	
	o/a Gifford Lecture Fund		1200.00	
1500	Debenture Fletcher Challenge Ltd.	1500.00		
800	Debenture General Finance Ltd.	800.00		
2000	Mortgage Hursthouse Properties Ltd.	2000.00		
700	N.B.N.Z. Savings Bank Investment a/c	700.00		
			5000.00	
				6200.00
	Fixed Assets			
2298	Library (at cost less depreciation)		2424.75	
129	Furniture & Fittings (do)		122.40	
480	Telescopes & Astronomical Equipment		480.00	
				3027.15
12331				$14502.12

AUDITOR'S REPORT

I have examined the books and vouchers of the Royal Astronomical Society of New Zealand (Inc.) I have received all the explanations I have required and in my opinion the accompanying Balance Sheet and Income and Expenditure Account fairly represent the financial position of the Society at 31 December 1983 and the results for the period ended on that date.

E.C.D. Watson J.P., F.C.A. Honorary Auditor 3/2/84

'Southern Stars' $4867 increase $1564
There were 4 issues paid for in 1983 including vol. 30/1 of 209 pages recording the Proceedings of the Second New Zealand Symposium on Photoelectric Photometry which cost $3120. Contributions towards the cost came from the Committee of the Symposium ($800, being balance of the Kingdon-Tomlinson grant), Auckland Observatory ($450), I.A.P.P.P. ($907) and the Ministry of Recreation and Sport ($500), totalling $2657. Sales of 'Southern Stars' including vol. 30/1 brought in a further $705.

'Newsletters' $607 increase $124
During the year a change in the method of producing the Newsletter was made from the cyclostyled sheets to an offset system. This has received favourable comment although the new method is about twice as costly.

Postages: $1827 increase $264
An unavoidable ever increasing expense. Posting 'Southern Stars' vol. 30/1 was more expensive than a normal issue.

Stationery: $775 increase $197
Mainly purchase of envelopes.

Advertising: $421 increase $315
Increased emphasis has been given to seeking advertisements in 'Southern Stars' and rates have been increased.

B.E. Stonehouse
Hon. Treasurer

SECTION REPORTS

COMPUTING SECTION:

A stimulating year which, apart from the normal requests for Rise/Set tables and Ephemerides, contained two very interesting projects. The first of these involved the search for rise times and azimuths of planets/stars that might coincide with a number of Maori stone artifacts built between 800 and 1300 years ago on Great Mercury Island. By applying corrections for precession etc., an estimate of the age of the artifacts was also attempted. This exercise originated from the author of a history of the island, due to be published early in 1984.

The second project required the development of a program to predict the altitude and azimuth of the Moon to closely predefined limits. The program will be used to direct the seeking mechanism of a remote lunar-acquisition unit to be installed in the Antarctic during 1984 by the PEL Atmospheric Division.

After many years, an effort is being made to launch a Computing Section Newsletter, albeit on an irregular basis. Brian Loader, Blenheim, has taken on the task of Editor. As with any exercise of this nature, considerable reliance will be placed on contributions from interested RASNZ members.

R. McIntosh
Director

OCCULTATION SECTION:

By the end of 1983 membership stood at about 70, a substantial increase primarily due to a greater interest from Australia, where over one-third of the membership resides.

During the report year, the number of total lunar occultations again rose, to over 1900, an increase of about 12% on 1982. In addition, two observers timed occultations of stars by minor planet (10) Hygiea in August and October. The Section continues to circulate predictions for these events, and further success is hoped for in 1984 despite difficulties in updating predictions with last-minute astrometry.

The number of grazing occultations successfully observed, while an increase from the previous year, still gives cause for concern, although the Jovian satellite phenomena program continues to grow slowly.

During the year contact was made with the Lunar Occultation sub-group of the BAA's Lunar Section, while our relationship in the minor planet field with the National Association of Planetary Observers in Australia was cemented.

Four quarterly and five special (minor planet) circulars were produced during 1983, together with the 1982 Annual Report. A guide to the observation of Jovian satellite events was prepared and distributed, as were predictions for 1983 and 1984. Lists of telescopes and observers used by the International Lunar Occultation Centre in Japan were circulated to observers for correction.

The quarter circulars are now reaching 20 pages in length and about 130 pages of material, including 41 minor planet occultation predictions, were published during the year. As a consequence of this and the necessity to go to a commercially printed A5 form of publication, the Section experienced a substantial deficit, resulting in a large subscription increase for 1984. Increases in membership and publications have meant that it is no longer possible for one person to carry out day to day running of the Section on a 'spare time' basis. A resolution of this difficulty will be sought during the coming year.

Papers produced during the year by Section members:

Blow, G.L. and Dunham, D.W., Just When You Thought It Was Safe To Forget About Asteroidal Satellites *Occ. Newsl. III (5)*, 102, 1983
Blow, G.L., Lunar Occultations, in *'Solar System Photometry Handbook'*, R. Genet (ed.) Willmann-Bell, 1983
Loader, B., Timing Occultations With A Digital Stopwatch, *Occ. Newsl. III, (4)*, 85, 1983
Loader, B., On Estimating Personal Equation and Its Accuracy, *Occ. Newsl. III, (4)*, 87, 1983

G.L. Blow
Director

VARIABLE STAR SECTION:

Membership 310, observations for the year 38,329 from 70 observers. Publications include 12 monthly Circulars, two issues of Publications (one in press), four Newsletters, one issue of charts, and several papers have been submitted to overseas journals. Frequent notes have been supplied to the Society's Newsletter on the activities of the Section.

Many special programmes have been run during the year in conjunction with various Tracking Stations and overseas astronomers. Special attention has been given to the various novae and supernovae discovered during the year. In particular the slow nova, Nova Mus 1983, has been very well followed and many requests for its light curve have been received. An important programme was that covering the recent supermaximum of VW Hydri which resulted in excellent coverage for the space agencies requesting our assistance. The service rendered to overseas professionals can best be gauged by the fact that the bill for telex messages and telephone calls during the year totalled just over $400.

Messrs. Dodson, Stephanopoulos, Venimore and Winnett have continued their work of preparing light curves and papers on individual stars. The IBM typewriter, for which a partial grant was received through the Society, has been in continuous use. The full report of the Section appears in Publ. 11, V.S.S., R.A.S.N.Z.

F.M. Bateson
Director

METEOR SECTION:

With the absence of the Director, the Section fell into caretaker hands mid-year. With membership standing at 50, three Bulletins were produced. The principal stimulus during the year was broughtabout by the International Halley Watch

Meteor Days in May and October. Although largely thwarted by the weather, many groups showed much interest and forwarded negative reports. Notable among these was the number of new young observers. An upsurge in interest has also been shown in micrometeorite work over the past year.

J.K. Parker and G.L. Blow
Caretaker Directors

AURORA SECTION:

The past twelve months have proved to be rather inactive for the Section. A number of bright aurorae were reported, although activity overall was considerably down on that reported for the previous few years. With the approach of solar minimum this was only to be expected.

The Director managed to get himself into the position of taking on more work (astronomical and other) than he could cope with and the negative result of this was that no circulars were published in 1983. Consequently there is currently a twelve month backlog of observations to analyse and publish. However, with the Director shedding much of his previous workload, it is anticipated that the Section will be fully serviced again from early 1984.

Membership currently stands at 17.

D.R. Goodman
Director

COMET AND MINOR PLANET SECTION:

The subscribing membership of the Section stands at 34.

Two ephemeris circulars were produced: no. 48 for Comet IRAS-Araki-Alcock 1983d and no. 49 for Comet Sugano-Saigusa-Fujikawa 1983e and Comet 1983d and also P/Comet Tempel I. No quarterly circulars were produced.

The directors' own astrometric programme continued at Mt. John University Observatory. 219 positions of 13 comets and 37 minor planets were published and the IAU Circulars and the Minor Planet Circulars. Four new asteroids were found though only two were followed for orbits. P/Comet Johnson (1983h) was recovered in June. Some observations of Comets IRAS-Araki-Alcock and Sugano-Saigusa-Fujikawa were useful in assisting successful radar observations of these close - passing comets. Once again we are indebted to the Carter Observatory for providing telex communications for urgent results.

A.C. Gilmore, P.M. Kilmartin
Directors

BOOK REVIEW

SOLAR SYSTEM PHOTOMETRY HANDBOOK

edited by Russell M. Genet

Published in 1983 by Willman-Bell, Inc.

This book is an excellent book for photoelectric observers and for those who seek guidance on photometric methods. There are two sections in the book, covering low and high speed photometry. In the low speed section, photometry of asteroids, planets, satellites, and comets is discussed together with lunar photometry, solar photometry and equipment needed to make low speed measurements.

The second section on high speed photometry covers occultations by planets and satellites, asteroids and lunar occultations, and a technical description of a portable high speed photoelectric photometer is detailed.

The book is edited by Russell Genet of the Fairborn Observatory and is an excellent collection of methods and observing programmes. Russell has produced many books on photoelectric observing techniques and this book is a valuable addition to the series. The book is prefaced by two forewards by astronomers Douglas S. Hall and David W. Dunham.

The first chapter by Richard P. Binzel covers photometry of asteroids. He gives basic parameters of asteroids, and gives details of how to determine a light curve and how to observe the colour differences during the asteroids' rotation. The chapter goes on to detail the period, and the amplitude of all asteroids with a visual magnitude greater than 10.5. Finally, Richard goes on to detail the reduction method to determine the standard magnitude and phase curve.

Chapter two on the photometry of planets and satellites is written by G. Wesley Lockwood. He considers solar and orbital phase curves, and the method of selecting comparison stars. In the observing technique he considers the sequence of observations, measurement of sky brightness which is important particularly in observing satellites close to the planet and concludes with examples on reduction methods.

Michael F. A'Hearn considers photometry of comets determining the basic requirements, and detailing the results. He considers broad band and narrow band photometry, and studies the emission features. This section of the book should be considered by all observers who plan to make observations of Halley's Comet, as the techniques and observing differ somewhat from conventional differential photometry of stellar objects. For instance, special filters are required, and minor modifications will be necessary to the photometer.

The chapter has an excellent bibliography.

Lunar photometry is next, described by Peter Hedervari. A table lists the albedos of the larger lunar craters, and the section goes on to describe the lunation curve, the reference points needed in the observing method and corrections that need to be made to determine the brightness of any point on the lunar surface relative to the radiance of the crater Aristarchus.

The chapter on solar photometry by Gary A. Chapman considers active region photometry, sunspot photometry, drift scan photometry and considers the present and future observations of the Sun that are being made at the San Fernando Observatory.

Jeffrey L. Hopkins describes the instrumentation required for low speed observations, considering the photometer head and supporting electronics. This is an excellent section for those contemplating the construction of a photometer.

Occultations of the planets and satellites are described by Robert L. Millis. He considers eclipses and mutual phenomena of the Galilean satellites. Early next year (1985) New Zealand observers are well placed for the next series of mutual phenomena and would be well advised to examine this section of the book.

Asteroid occultations by Alan W. Harris details observational methods and determinations of occultation predictions for asteroid observations.

Graham Blow of Carter Observatory covers Lunar Occultations. He considers the diffraction of the stellar light at the lunar limb, and from this data he considers how the light curve is modified as the diameter of the star changes. This is a powerful method of determining the diameter of stars which are occulted by the Moon. High speed photometry requires a time resolution of better than one millisecond and consequently the equipment required is more sophisticated than conventional photoelectric photometry. Notwithstanding, several amateur and professional groups have undertaken this work in New Zealand.

The final chapter, by Peter C. Chen, describes a prototype portable high speed photometer. The reduction equipment is microprocessor based and line diagrams detail the components required.

In conclusion, this book is well presented, and has many references to support design and observational papers. I can recommend it to all photoelectric observers and for those who intend to pursue this interesting field.

W.H. Allen
Adams Lane Observatory
Blenheim

BOOK REVIEW

ASTRONOMICAL TABLES OF THE SUN, MOON AND PLANETS

by Jean Meeus

Published in 1983 by Willman-Bell, Inc.

Jean Meeus, a meteorologist at the Brussels Airport and with special interests in spherical and mathematical astronomy has, since 1966, produced a number of well-known and popular astronomical books. His latest publication is "Astronomical Tables of the Sun, Moon and Planets".

The 400-odd pages of information regarding planetary phenomena is contained in some 96 tables of data. Most of the individual tables themselves are spread over many pages.

Some of the tables cover phenomena for the years 1951-2050 while those of a more historical significance start from earlier dates.

The book is divided into nine sections, each of which is devoted to a number of aspects relevant to the Section title:

Section 1: Planetary Phenomena 1976-2005

Section 2: Oppositions of Mars 0-3010

Section 3: Equinoxes and Solstices (Earth)
Duration of Astronomical Seasons
in Days -3000 to +6000

Section 4: Phases of the Moon

Section 5: Occultations of Planets and Bright
Stars by the Moon 1980-2000

Section 6: Sunspot Activity 1749-1981

Section 7: Other Tables

Section 8: Bibliography

Section 9: Index

Section 7 contains many tables of data of historical interest, i.e. Transits of Venus 1300-4100, plus others of

more immediacy, i.e. Solar and Lunar eclipses 1951 to 2050.

Each section starts with general comments about its content, plus interesting features that readers can check out for themselves. If more information is required, reference to the bibliography in Section 8 will list the source documentation.

Of special interest to many people will be Section 5. The introductory general comments describe how to use the occultation tables, and the simple formulae that allow the reader to calculate the "local" conditions under which a specific occultation may occur. Many worked examples are given together with HP-67, HP-41c and TI-59 programmable calculator programs to make life a little easier for owners of these instruments. Microcomputer owners should not despair either, as all the formulae are given in the text.

Although most of the data presented can be derived from first principles using a computer, the arrangement of the tables plus their immediate availability allows the reader rapidly to compare phenomena for different dates and discover relationships that are rarely obvious when dealing with isolated calculations.

In "Astronomical Tables of the Sun, Moon and Planets" Jean Meeus has produced a book that, although basically of the "reference" variety, is also well suited for browsing. Both armchair and serious astronomers will find a wealth of information relating to the orbital machinations of our planetary neighbours.

R. McIntosh

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